

EXHIBIT 4



US006397136B1

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Breed et al.

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(45) Date of Patent: **May 28, 2002**

(54) **SYSTEM FOR DETERMINING THE OCCUPANCY STATE OF A SEAT IN A VEHICLE**

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(Under 37 CFR 1.47)

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(63) Continuation-in-part of application No. 09/382,406, filed on Aug. 24, 1999, which is a continuation-in-part of application No. 08/919,823, filed on Aug. 28, 1997, now Pat. No. 5,943,295, which is a continuation-in-part of application No. 08/798,029, filed on Feb. 6, 1997, now abandoned.
(60) Provisional application No. 60/136,163, filed on May 27, 1999.

(51) Int. Cl.⁷ **B60R 21/22**
(52) U.S. Cl. **701/45; 280/735; 180/273**
(58) Field of Search **701/45, 46, 47, 701/49; 280/734, 735; 180/268, 271, 273; 318/286, 466, 467, 468**

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Primary Examiner—William A. Cuchlinski, Jr.

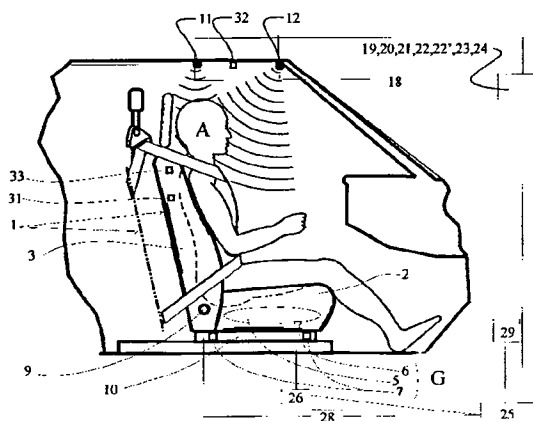
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(57) **ABSTRACT**

System for determining the occupancy of a seat in a vehicle using a variety of transducers and pattern recognition technologies and techniques that applies to any combination of transducers that provide information about seat occupancy. These include weight sensors, capacitive sensors, inductive sensors, ultrasonic, optical, electromagnetic, motion, infrared, and radar among others. The system includes a processor coupled to the transducers for receiving the data from the transducers and processing the data to obtain an output indicative of the current occupancy state of the seat. An algorithm is resident in the processor and is created from a plurality of data sets, each representing a different occupancy state of the seat and being formed from data from the transducers while the seat is in that occupancy state. The algorithm produces the output indicative of the current occupancy state of the seat upon inputting a data set representing the current occupancy state of the seat and being formed from data from the transducers. The algorithm may be a neural network or neural fuzzy algorithm generated by an appropriate algorithm-generating program.

70 Claims, 12 Drawing Sheets



US 6,397,136 B1

Page 2

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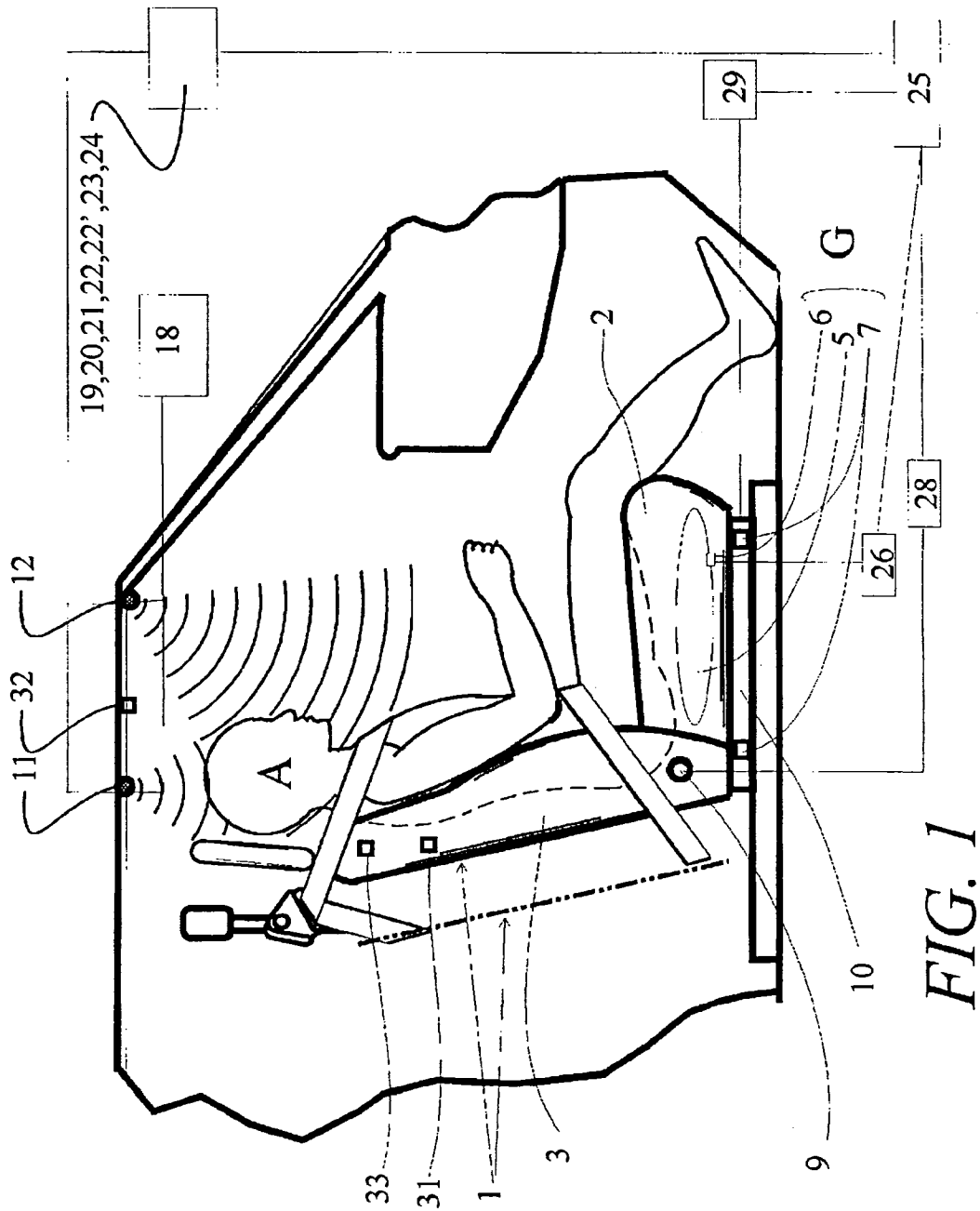


FIG. 1

U.S. Patent

May 28, 2002

Sheet 2 of 12

US 6,397,136 B1

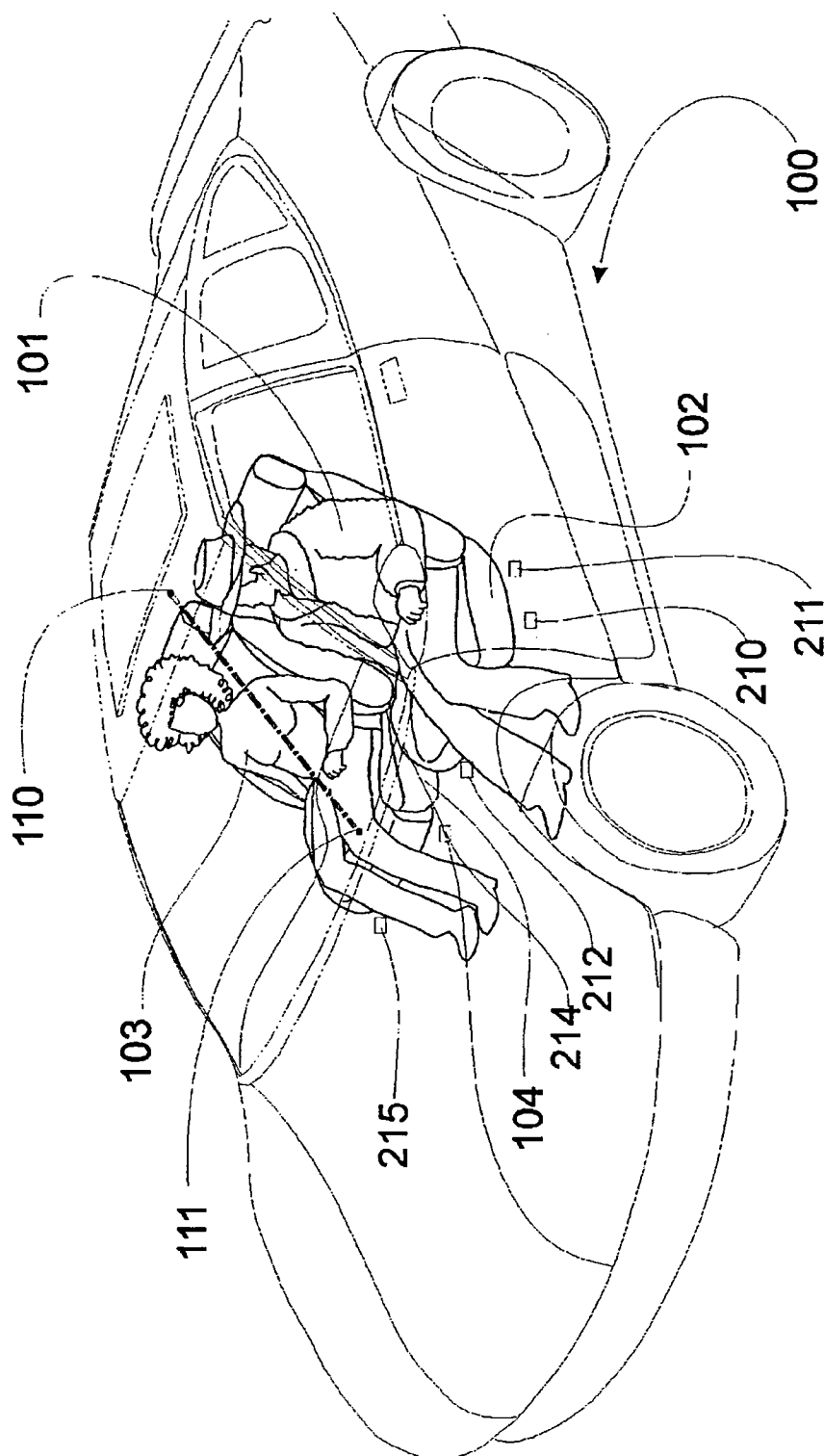


FIG. 2

U.S. Patent

May 28, 2002

Sheet 3 of 12

US 6,397,136 B1

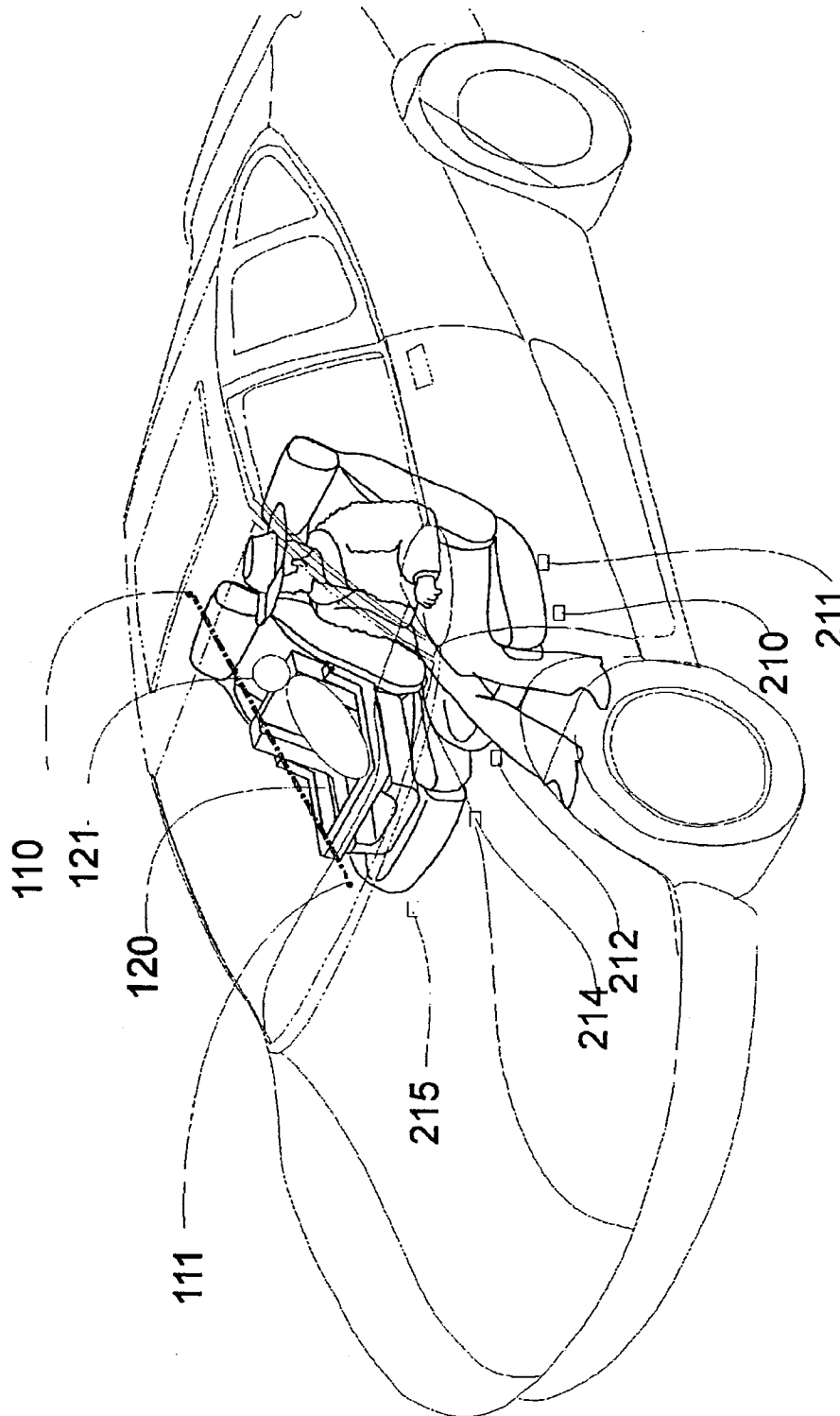


FIG. 3

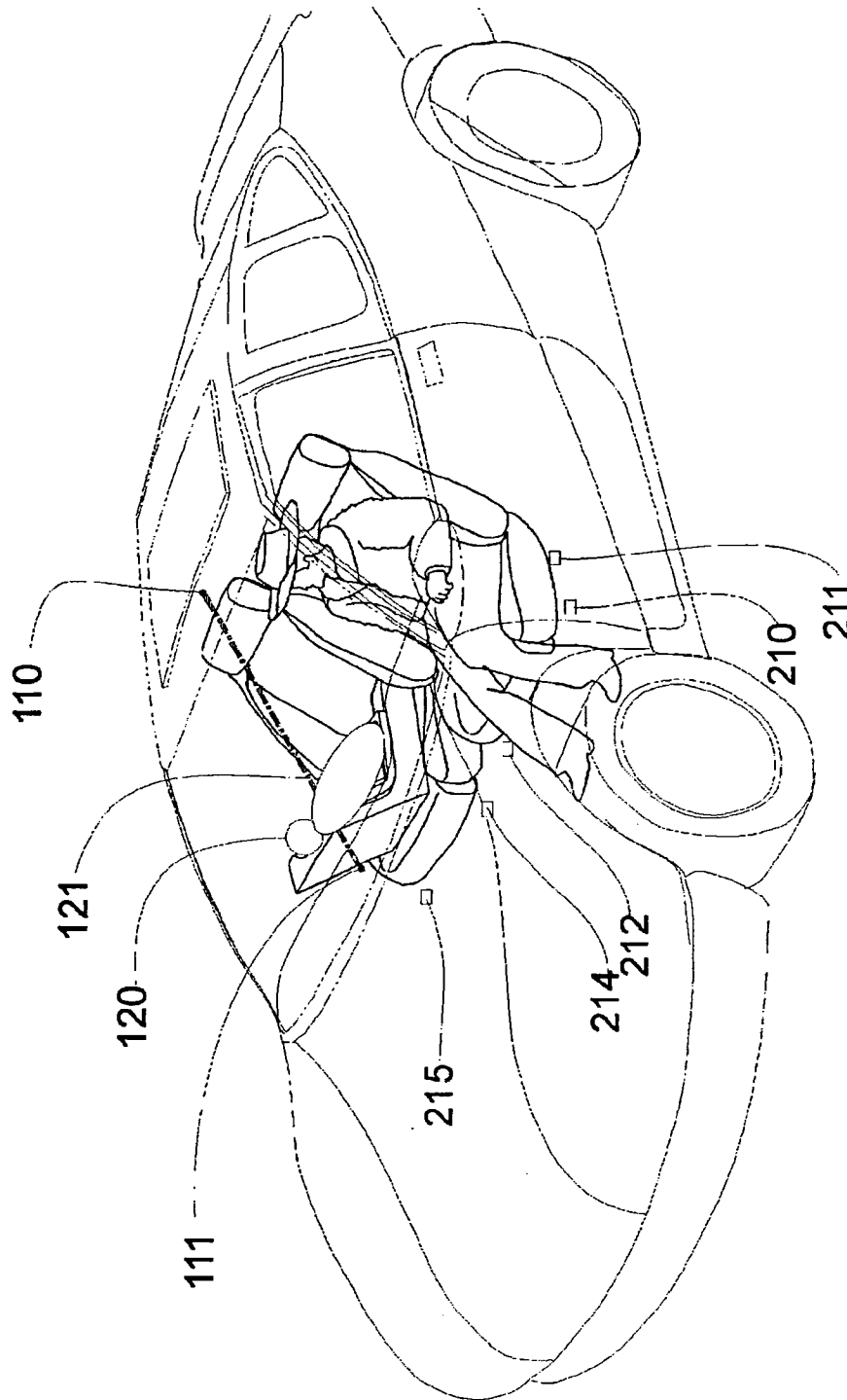


FIG. 4

U.S. Patent

May 28, 2002

Sheet 5 of 12

US 6,397,136 B1

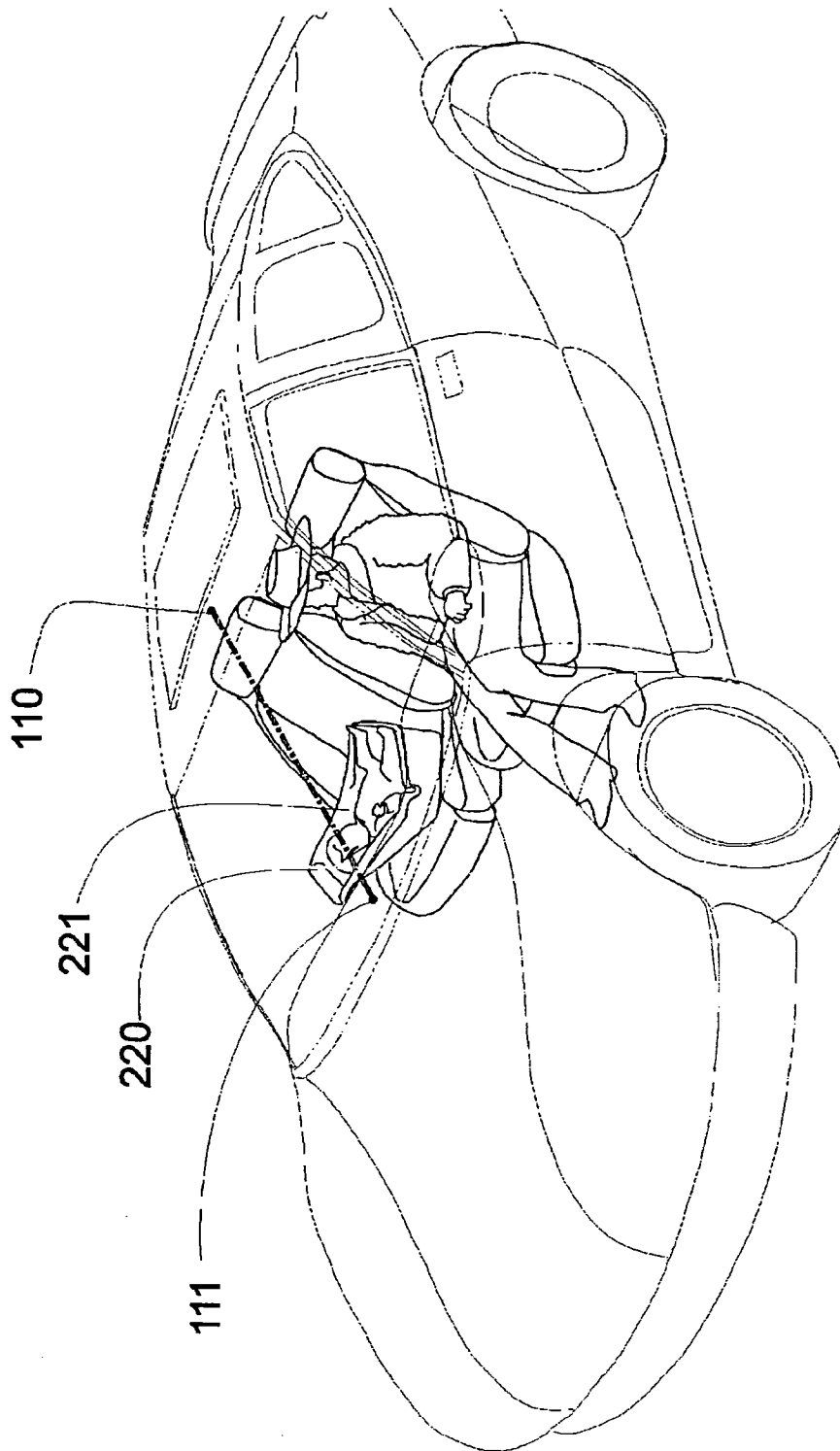


FIG. 5

U.S. Patent

May 28, 2002

Sheet 6 of 12

US 6,397,136 B1

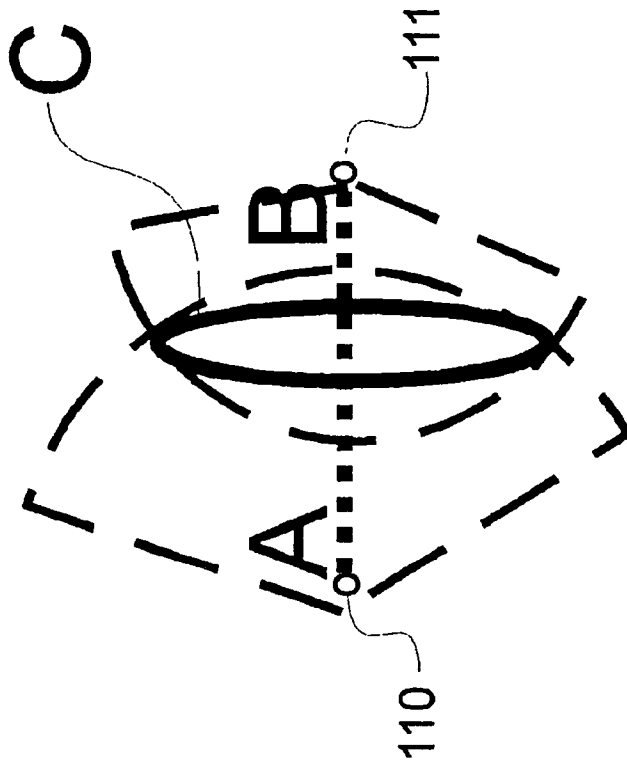


FIG. 6

U.S. Patent

May 28, 2002

Sheet 7 of 12

US 6,397,136 B1

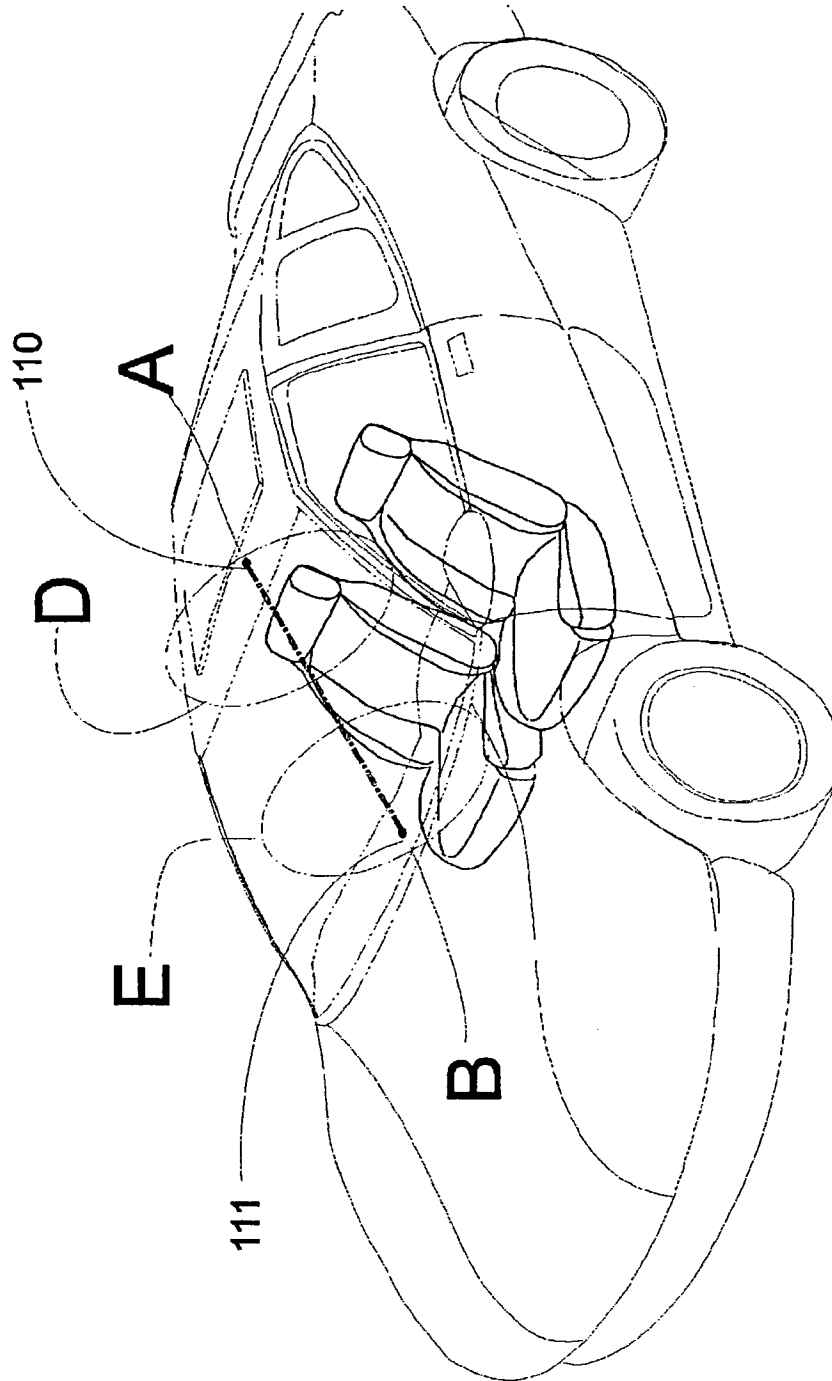


FIG. 7

U.S. Patent

May 28, 2002

Sheet 8 of 12

US 6,397,136 B1

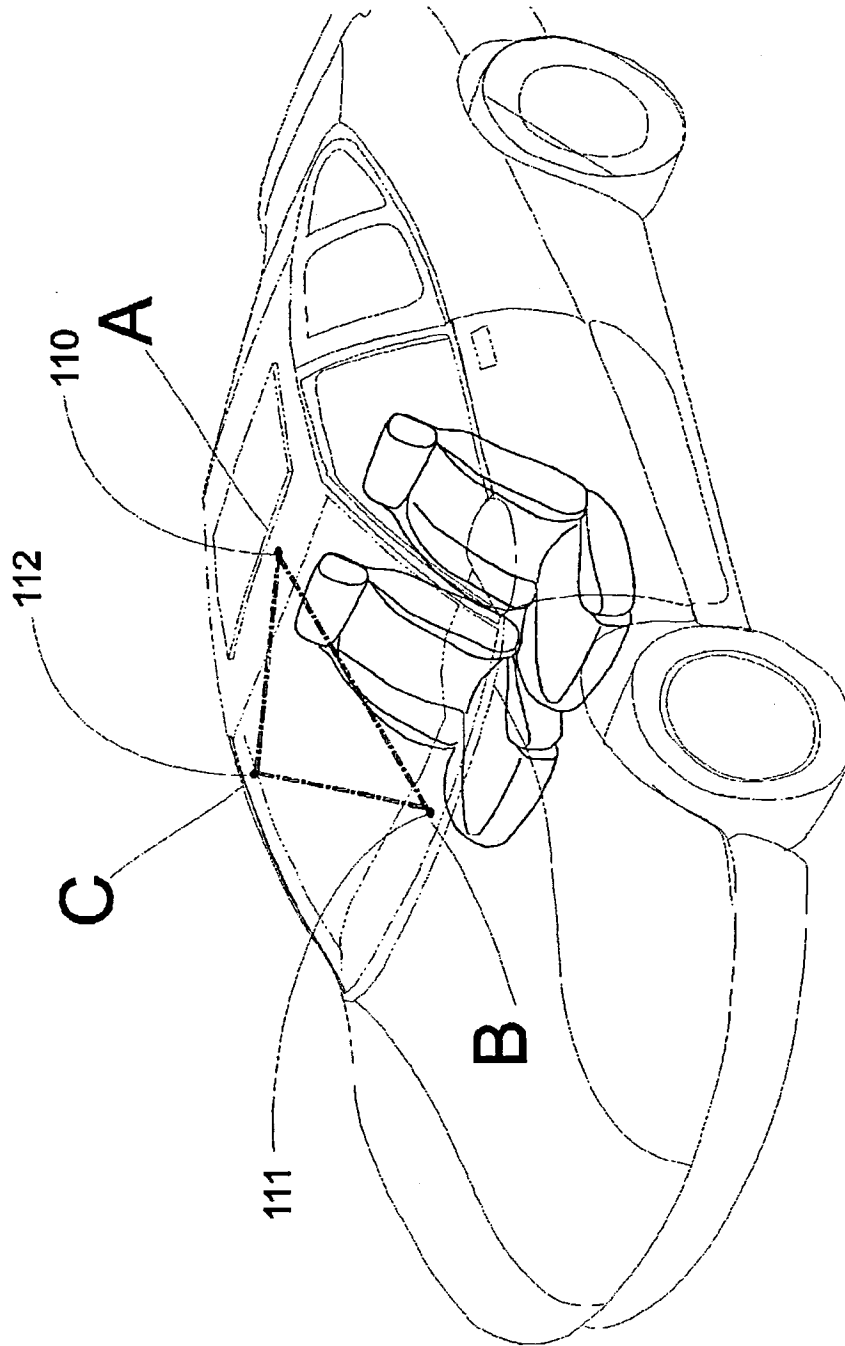


FIG. 8

U.S. Patent

May 28, 2002

Sheet 9 of 12

US 6,397,136 B1

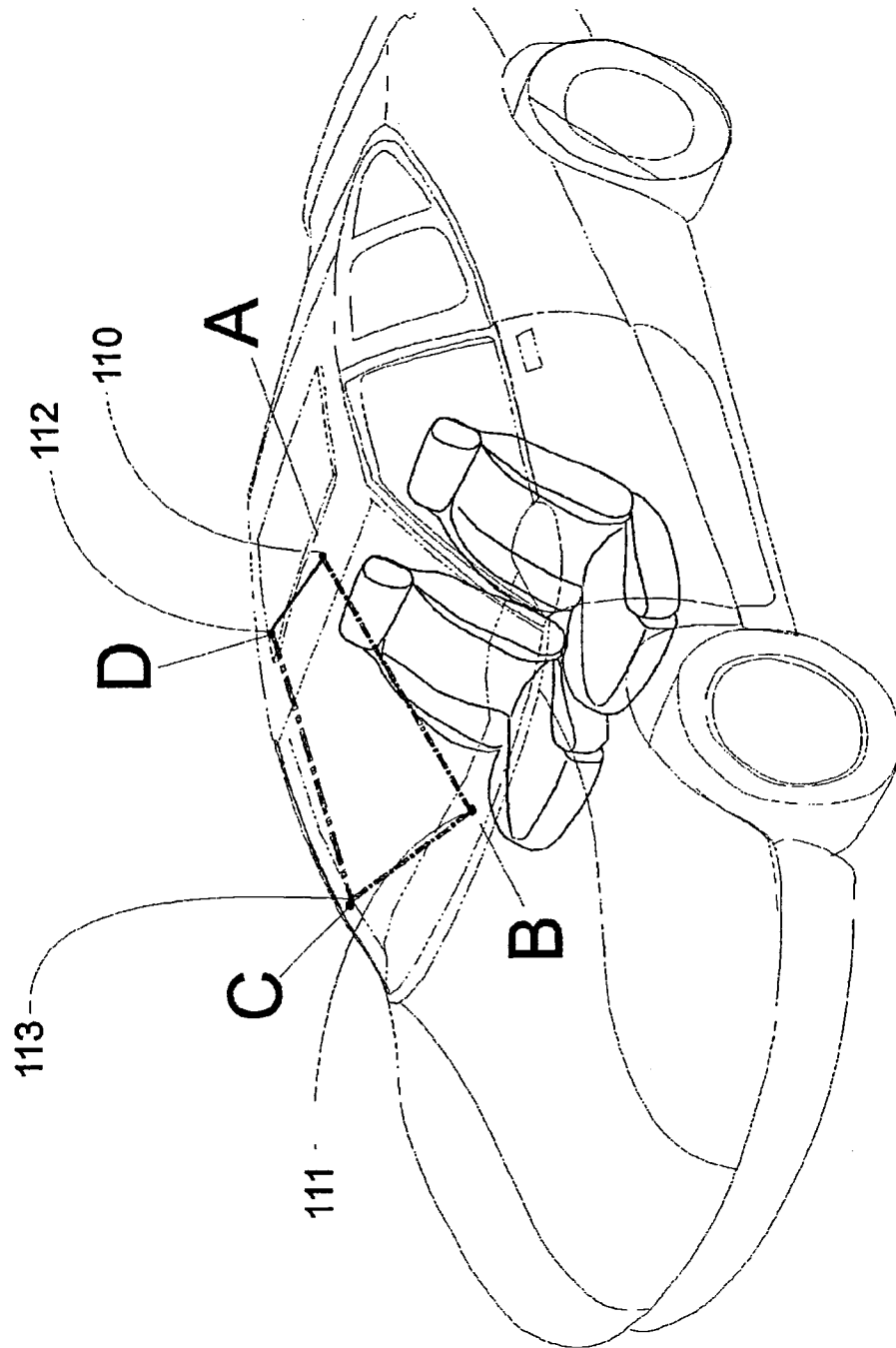


FIG. 9

U.S. Patent

May 28, 2002

Sheet 10 of 12

US 6,397,136 B1

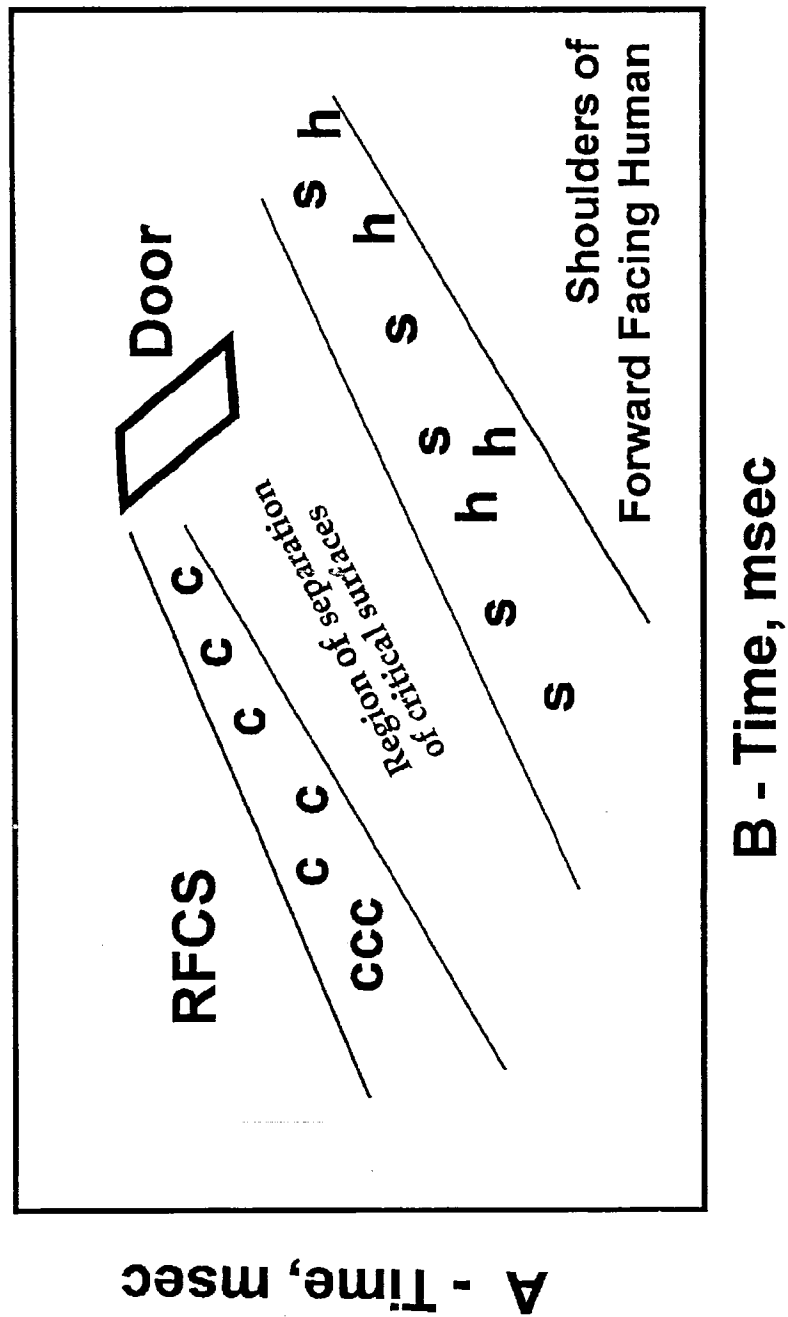


FIG. 10

U.S. Patent

May 28, 2002

Sheet 11 of 12

US 6,397,136 B1

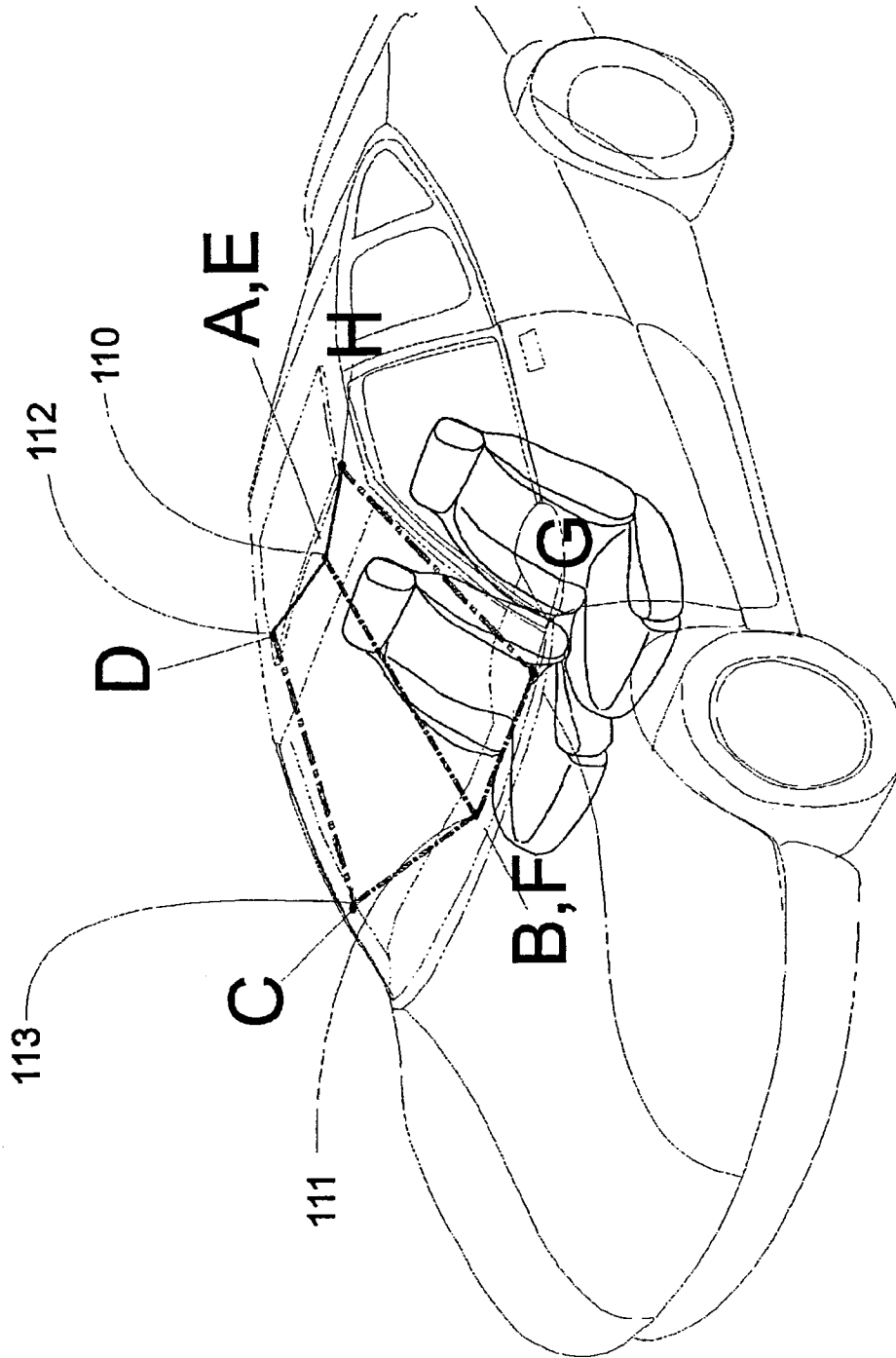


FIG. 11

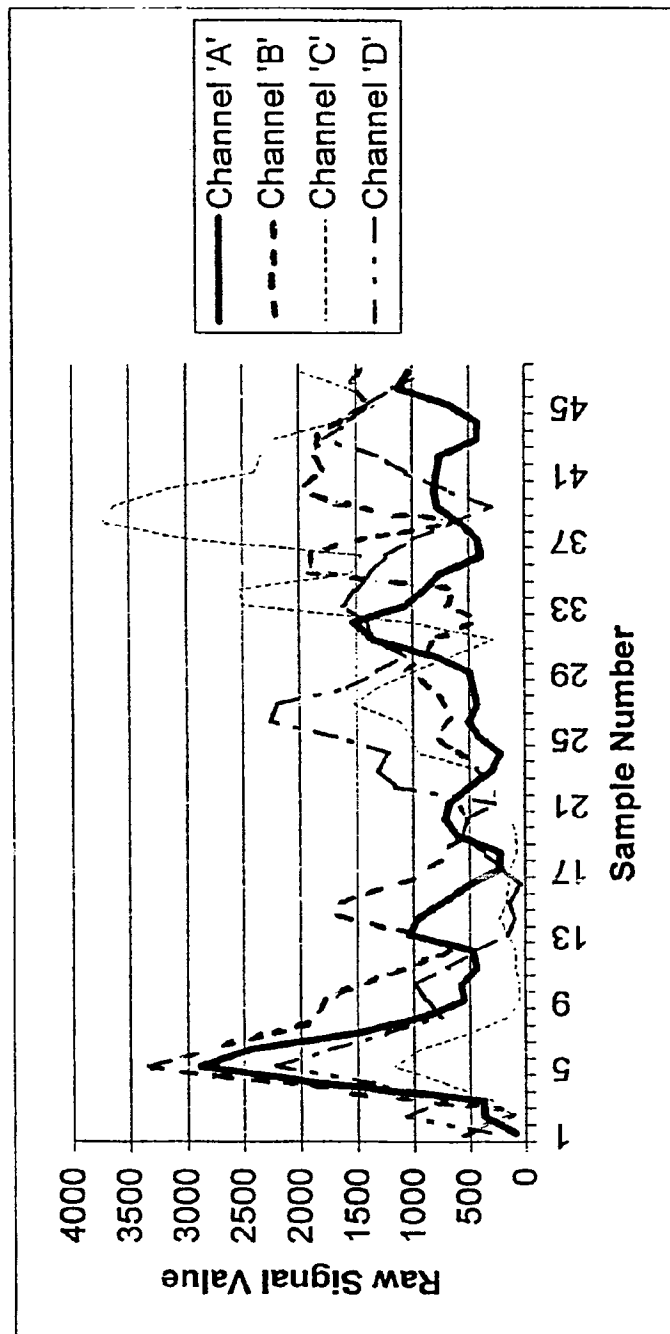
U.S. Patent

May 28, 2002

Sheet 12 of 12

US 6,397,136 B1

FIG. 12



US 6,397,136 B1

1

SYSTEM FOR DETERMINING THE OCCUPANCY STATE OF A SEAT IN A VEHICLE

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority under 35 U.S.C. §119(c) of U.S. provisional patent application Ser. No. 60/136,163 filed May 27, 1999.

This application is continuation-in-part of U.S. patent application Ser. No. 09/382,406 filed Aug. 24, 1999 which is a continuation-in-part of U.S. patent application Ser. No. 08/919,823, filed Aug. 28, 1997 now U.S. Pat. No. 5,943, 295, which in turn is a continuation-in-part of U.S. patent application Ser. No. 08/798,029 filed Feb. 6, 1997, now abandoned.

This application is related to: (i) U.S. Pat. No. 5,653,462 entitled "Vehicle Occupant Position and Velocity Sensor" filed Jul. 21, 1995, which is a continuation of U.S. patent application Ser. No. 08/040,978 filed Mar. 31, 1993, now abandoned, which in turn is a continuation of U.S. patent application Ser. No. 07/878,571 filed May 5, 1992, now abandoned; (ii) U.S. Pat. No. 5,829,782 entitled "Vehicle Interior Identification and Monitoring System" filed May 9, 1994; (iii) U.S. Pat. No. 5,845,000 entitled "Optical Identification and Monitoring System Using Pattern Recognition for Use with Vehicles" filed Jun. 7, 1995; (iv) U.S. Pat. No. 5,822,707 entitled "Automatic Vehicle Seat Adjuster" filed Jun. 7, 1995; (v) U.S. Pat. No. 5,748,473 entitled "Automatic Vehicle Seat Adjuster" filed June 7, 1995; and, (vi) U.S. Pat. No. 5,835,613 entitled "Optical Identification and Monitoring System Using Pattern Recognition for use with Vehicles" filed Jun. 7, 1995, which are all incorporated by reference herein.

FIELD OF THE INVENTION

The present invention relates generally to the fields of sensing, detecting, monitoring and/or identifying various objects, and parts thereof, which are located within the passenger compartment of a motor vehicle. In particular, the present invention relates to an efficient and highly reliable system for evaluating the occupancy of a vehicle by detecting the presence and optionally orientation of objects in the seats of the passenger compartment, e.g., a rear facing child seat (RFCS) situated in the passenger compartment in a location where it may interact with a deploying occupant protection apparatus, such as an airbag, and/or for detecting an out-of-position occupant. The system permits the control and selective suppression of deployment of the occupant protection apparatus when the deployment may result in greater injury to the occupant than the crash forces themselves. This is accomplished in part through a specific placement of transducers of the system, the use of a pattern recognition system, possibly a trained neural network, and/or a novel analysis of the signals from the transducers.

The application of the occupant position sensor to a new automobile vehicle model is called applications engineering. Applications engineering of occupant sensors comprises, inter alia, determining the location of the transducers, designing the transducer holders, determining the wiring layout, performing a tolerance study on the transducer locations and angular orientation, designing the circuits for the particular vehicle model, interfacing or integrating the circuits into the vehicle electronic system, and adapting the occupant sensor system to the particular vehicle model.

All of the above aspects of application engineering, with the exception of the system adaptation, are standard pro-

2

cesses that do not differ significantly from the application engineering of any electronic system to a new vehicle model. The system adaptation, however, is unique in that it requires considerable skill and expertise and the use of novel technologies to create a system that is optimized for a particular vehicle.

BACKGROUND OF THE INVENTION

1. Prior Art on Sensing of Out-of-position Occupants and Rear Facing Child Seats

Whereas thousands of lives have been saved by airbags, a large number of people have also been injured, some seriously, by the deploying airbag, and thus significant improvements to the airbag system are necessary. As discussed in detail in one or more of the patents and patent applications cross-referenced above, for a variety of reasons, vehicle occupants may be too close to the airbag before it deploys and can be seriously injured or killed as a result of any deployment thereof. Also, a child in a rear facing child seat which is placed on the right front passenger seat is in danger of being seriously injured if the passenger airbag deploys. For these reasons and, as first publicly disclosed in Breed, D. S. "How Airbags Work" presented at the International Conference on Seatbelts and Airbags in 1993, in Canada, occupant position sensing and rear facing child seat detection is required in order to minimize the damages caused by deploying airbags. It also may be required in order to minimize the damage caused by the deployment of other types of occupant protection and/or restraint devices which might be installed in the vehicle.

Initially, these systems will solve the out-of-position occupant and the rear facing child seat problems related to current airbag systems and prevent unneeded and unwanted airbag deployments when a front seat is unoccupied. However, airbags are now under development to protect rear seat occupants in vehicle crashes and all occupants in side impacts. A system is therefore needed to detect the presence of occupants, determine if they are out-of-position (defined below) and to identify the presence of a rear facing child seat in the rear seat. Future automobiles are expected to have eight or more airbags as protection is sought for rear seat occupants and from side impacts. In addition to eliminating the disturbance and possible harm of unnecessary airbag deployments, the cost of replacing these airbags will be excessive if they all deploy in an accident needlessly.

Inflators now exist which will adjust the amount of gas flowing to or from the airbag to account for the size and position of the occupant and for the severity of the accident. The vehicle identification and monitoring system (VIMS) discussed in U.S. Pat. No. 5,829,782, and U.S. patent application Ser. No. 08/798,029 filed Feb. 6, 1997 among others, will control such inflators based on the presence and position of vehicle occupants or of a rear facing child seat. The instant invention is concerned with the process of adapting the vehicle interior monitoring systems to a particular vehicle model and achieving a high system accuracy and reliability as discussed in greater detail below.

The automatic adjustment of the deployment rate of the airbag based on occupant identification and position and on crash severity has been termed "smart airbags". Central to the development of smart airbags is the occupant identification and position determination systems described in the above-referenced patents and patent applications and to the methods described herein for adapting those systems to a particular vehicle model. To complete the development of smart airbags, an anticipatory crash detecting system such as disclosed in U.S. patent application Ser. No. 08/247,760 filed May 23, 1994 is also desirable. Prior to the implemen-

US 6,397,136 B1

3

tation of anticipatory crash sensing, the use of a neural network smart crash sensor which identifies the type of crash and thus its severity based on the early part of the crash acceleration signature should be developed and thereafter implemented. U.S. Pat. No. 5,684,701 (Breed) describes a crash sensor based on neural networks. This crash sensor, as with all other crash sensors, determines whether or not the crash is of sufficient severity to require deployment of the airbag and, if so, initiates the deployment. A neural network based on a smart airbag crash sensor could also be designed to identify the crash and categorize it with regard to severity thus permitting the airbag deployment to be matched not only to the characteristics and position of the occupant but also the severity and timing of the crash itself (this being described in U.S. patent application Ser. No. 08/798,029 referenced above).

The need for an occupant out-of-position sensor has also been observed by others and several methods have been described in certain U.S. patents for determining the position of an occupant of a motor vehicle. However, no patents have been found that describe the methods of adapting such sensors to a particular vehicle model to obtain high system accuracy. Each of these systems will be discussed below and have significant limitations.

In White et al. (U.S. Pat. No. 5,071,160), for example, a single acoustic sensor and detector is described and, as illustrated, is mounted lower than the steering wheel. White et al. correctly perceive that such a sensor could be defeated, and the airbag falsely deployed, by an occupant adjusting the control knobs on the radio and thus they suggest the use of a plurality of such sensors. White et al. does not disclose where the such sensors would be mounted, other than on the instrument panel below the steering wheel, or how they would be combined to uniquely monitor particular locations in the passenger compartment and to identify the object(s) occupying those locations. The adaptation process to vehicles is not described.

Mattes et al. (U.S. Pat. No. 5,118,134) describe a variety of methods for measuring the change in position of an occupant including ultrasonic, active or passive infrared radiation and microwave radar sensors, and an electric eye. The use of these sensors is to measure the change in position of an occupant during a crash and they use that information to assess the severity of the crash and thereby decide whether or not to deploy the airbag. They are thus using the occupant motion as a crash sensor. No mention is made of determining the out-of-position status of the occupant or of any of the other features of occupant monitoring as disclosed in the above-referenced patents and/or patent applications. It is interesting to note that nowhere does Mattes et al. discuss how to use a combination of ultrasonic sensors/transmitters to identify the presence of a human occupant and then to find his/her location in the passenger compartment.

The object of an occupant out-of-position sensor is to determine the location of, e.g., the head and/or chest of the vehicle occupant in the passenger compartment to enable the location of the head and/or chest to be determined relative to the occupant protection apparatus, e.g., airbag, since it is the impact of either the head or chest with the deploying airbag which can result in serious injuries. Both White et al. and Mattes et al. disclose only lower mounting locations of their sensors which are mounted in front of the occupant such as on the dashboard or below the steering wheel. Both such mounting locations are particularly prone to detection errors due to positioning of the occupant's hands, arms and legs. This would require at least three, and preferably more, such sensors and detectors and an appropriate logic circuitry

4

which ignores readings from some sensors if such readings are inconsistent with others, for the case, for example, where the driver's arms are the closest objects to two of the sensors. The determination of the proper transducer mounting locations, aiming and field angles for a particular vehicle model are not disclosed in either White et al. or Mattes et al. and are part of the vehicle model adaptation process described herein.

White et al. also describe the use of error correction circuitry, without defining or illustrating the circuitry, to differentiate between the velocity of one of the occupant's hands, as in the case where he/she is adjusting the knob on the radio, and the remainder of the occupant. Three ultrasonic sensors of the type disclosed by White et al. might, in some cases, accomplish this differentiation if two of them indicated that the occupant was not moving while the third was indicating that he or she was moving. Such a combination, however, would not differentiate between an occupant with both hands and arms in the path of the ultrasonic transmitter at such a location that they were blocking a substantial view of the occupant's head or chest. Since the sizes and driving positions of occupants are extremely varied, trained pattern recognition systems, such as neural networks, are required when a clear view of the occupant, unimpeded by his/her extremities, cannot be guaranteed. White et al. do not suggest the use of such neural networks.

Fujita et al., in U.S. Pat. No. 5,074,583, describe another method of determining the position of the occupant but do not use this information to control and suppress deployment of an airbag if the occupant is out-of-position, or if a rear facing child seat is present. In fact, the closer that the occupant gets to the airbag, the faster the inflation rate of the airbag is according to the Fujita et al. patent, which thereby increases the possibility of injuring the occupant. Fujita et al. do not measure the occupant directly but instead determine his or her position indirectly from measurements of the seat position and the vertical size of the occupant relative to the seat. This occupant height is determined using an ultrasonic displacement sensor mounted directly above the occupant's head.

It is important to note that in all cases in the above-cited prior art, except those assigned to the current assignee of the instant invention, no mention is made of the method of determining transducer location, deriving the algorithms or other system parameters that allow the system to accurately identify and locate an object in the vehicle. In contrast, in one implementation of the instant invention, the return ultrasonic echo pattern over several milliseconds corresponding to the entire portion of the passenger compartment volume of interest is analyzed from multiple transducers and sometimes combined with the output from other transducers, providing distance information to many points on the items occupying the passenger compartment.

Many of the teachings of this invention are based on pattern recognition technologies as taught in numerous textbooks and technical papers. Central to the diagnostic teachings of this invention is the manner in which the diagnostic module determines a normal pattern from an abnormal pattern and the manner in which it decides what data to use from the vast amount of data available. This is accomplished using pattern recognition technologies, such as artificial neural networks, and training. The theory of neural networks including many examples can be found in several books on the subject including: *Techniques And Application Of Neural Networks*, edited by Taylor, M. and Lisboa, P., Ellis Horwood, West Sussex, England, 1993;

US 6,397,136 B1

5

Naturally Intelligent Systems, by Caudill, M. and Butler, C., MIT Press, Cambridge Mass., 1990; J. M. Zaruda, *Introduction to Artificial Neural Systems*, West publishing Co., New York, 1992 and, *Digital Neural Networks*, by Kung, S. Y., PTR Prentice Hall, Englewood Cliffs, N.J., 1993, Eberhart, R., Simpson, P. and Dobbins, R., *Computational Intelligence PC Tools* Academic Press, Inc., 1996, Orlando, Fla., all of which are included herein by reference. The neural network pattern recognition technology is one of the most developed of pattern recognition technologies.

Other patents describing occupant sensor systems include U.S. Pat. No. 5,482,314 (Corrado et al.) and U.S. Pat. No. 5,890,085 (Corrado et al.). These patents describe a system for sensing the presence, position and type of an occupant in a seat of a vehicle for use in enabling or disabling a related airbag activator. A preferred implementation of the system includes two or more different but collocated sensors which provide information about the occupant and this information is fused or combined in a microprocessor circuit to produce an output signal to the airbag controller. According to Corrado et al., the fusion process produces a decision as to whether to enable or disable the airbag with a higher reliability than a single phenomena sensor or non-fused multiple sensors. By fusing the information from the sensors to make a determination as to the deployment of the airbag, each sensor has only a partial effect on the ultimate deployment determination. The sensor fusion process is a crude pattern recognition process based on deriving the fusion "rules" by a trial and error process.

The sensor fusion method of Corrado et al. requires that information from the sensors be combined prior to processing in the microprocessor, e.g., entry into the algorithm thereof. This combination could be found to unnecessarily complicate the processing of the data from the sensors and other data processing methods might provide better results. For example, as discussed more fully below, it has been found to be advantageous to use a more efficient pattern recognition algorithm such as a neural network or fuzzy logic algorithm which is arranged to receive a separate stream of data from each sensor, without that data being combined with data from the other sensors (as in done in Corrado et al.). In this regard, it is critical to appreciate that sensor fusion is a form of pattern recognition but is not a neural network and that significant and fundamental differences exist between sensor fusion and neural networks. Thus, some embodiments of the invention described below differ from that of Corrado et al. because they include a microprocessor which is arranged to accept only a separate stream of data from each sensor such that the stream of data from the sensors are not combined with one another. Further, the microprocessor processes each separate stream of data independent of the processing of the other streams of data (i.e., without the use of any fusion matrix as in Corrado et al.).

2. Definitions

The use of pattern recognition, or more particularly how it is used, is central to the instant invention. In the above-cited prior art, except in that assigned to the current assignee of the instant invention, pattern recognition which is based on training, as exemplified through the use of neural networks, is not mentioned for use in monitoring the interior passenger compartment or exterior environments of the vehicle. Thus, the methods used to adapt such systems to a vehicle are also not mentioned.

"Pattern recognition" as used herein will generally mean any system which processes a signal that is generated by an object (e.g., representative of a pattern of returned or

6

received impulses, waves or other physical property specific to and/or characteristic of and/or representative of that object) or is modified by interacting with an object, in order to determine to which one of a set of classes that the object belongs. Such a system might determine only that the object is or is not a member of one specified class, or it might attempt to assign the object to one of a larger set of specified classes, or find that it is not a member of any of the classes in the set. The signals processed are generally a series of electrical signals coming from transducers that are sensitive to acoustic (ultrasonic) or electromagnetic radiation (e.g., visible light, infrared radiation, capacitance or electric and magnetic fields), although other sources of information are frequently included. Pattern recognition systems generally involve the creation of the set of rules that permit the pattern to be recognized. These rules can be created by fuzzy logic systems, statistical correlations, or through sensor fusion methodologies as well as by trained pattern recognition systems such as neural networks.

A trainable or a trained pattern recognition system as used herein generally means a pattern recognition system which is taught to recognize various patterns constituted within the signals by subjecting the system to a variety of examples. The most successful such system is the neural network. Thus, to generate the pattern recognition algorithm, test data is first obtained which constitutes a plurality of sets of returned waves, or wave patterns, from an object (or from the space in which the object will be situated in the passenger compartment, i.e., the space above the seat) and an indication of the identity of that object, (e.g., a number of different objects are tested to obtain the unique wave patterns from each object). As such, the algorithm is generated, and stored in a computer processor, and which can later be applied to provide the identity of an object based on the wave pattern being received during use by a receiver connected to the processor and other information. For the purposes here, the identity of an object sometimes applies to not only the object itself but also to its location and/or orientation in the passenger compartment. For example, a rear facing child seat is a different object than a forward facing child seat and an out-of-position adult is a different object than a normally seated adult.

To "identify" as used herein will generally mean to determine that the object belongs to a particular set or class. The class may be one containing, for example, all rear facing child seats, one containing all human occupants, or all human occupants not sitting in a rear facing child seat depending on the purpose of the system. In the case where a particular person is to be recognized, the set or class will contain only a single element, i.e., the person to be recognized.

An "object" in a vehicle or an "occupant" or "occupying item" of a seat may be a living occupant such as a human or a dog, another living organism such as a plant, or an inanimate object such as a box or bag of groceries or an empty child seat.

"Out-of-position" as used for an occupant will generally mean that the occupant, either the driver or a passenger, is sufficiently close to the occupant protection apparatus (airbag) prior to deployment that he or she is likely to be more seriously injured by the deployment event itself than by the accident. It may also mean that the occupant is not positioned appropriately in order to attain beneficial, restraining effects of the deployment of the airbag. As for the occupant being too close to the airbag, this typically occurs when the occupant's head or chest is closer than some distance such as about 5 inches from the deployment door of

US 6,397,136 B1

7

the airbag module. The actual distance value where airbag deployment should be suppressed depends on the design of the airbag module and is typically farther for the passenger airbag than for the driver airbag.

"Transducer" as used herein will generally mean the combination of a transmitter and a receiver. In some cases, the same device will serve both as the transmitter and receiver while in others two separate devices adjacent to each other will be used. In some cases, a transmitter is not used and in such cases transducer will mean only a receiver. Transducers include, for example, capacitive, inductive, ultrasonic, electromagnetic (antenna, CCD, CMOS arrays), weight measuring or sensing devices.

"Adaptation" as used here represents the method by which a particular occupant sensing system is designed and arranged for a particular vehicle model. It includes such things as the process by which the number, kind and location of various transducers is determined. For pattern recognition systems, it includes the process by which the pattern recognition system is taught to recognize the desired patterns. In this connection, it will usually include (1) the method of training, (2) the makeup of the databases used for training, testing, and validating the particular system, or, in the case of a neural network, the particular network architecture chosen, (3) the process by which environmental influences are incorporated into the system, and (4) any process for determining the pre-processing of the data or the post processing of the results of the pattern recognition system. The above list is illustrative and not exhaustive. Basically, adaptation includes all of the steps that are undertaken to adapt transducers and other sources of information to a particular vehicle to create the system which accurately identifies and determines the location of an occupant or other object in a vehicle.

In the description herein on anticipatory sensing, the term "approaching" when used in connection with the mention of an object or vehicle approaching another will generally mean the relative motion of the object toward the vehicle having the anticipatory sensor system. Thus, in a side impact with a tree, the tree will be considered as approaching the side of the vehicle and impacting the vehicle. In other words, the coordinate system used in general will be a coordinate system residing in the target vehicle. The "target" vehicle is the vehicle which is being impacted. This convention permits a general description to cover all of the cases such as where (i) a moving vehicle impacts into the side of a stationary vehicle, (ii) where both vehicles are moving when they impact, or (iii) where a vehicle is moving, sideways into a stationary vehicle, tree or wall. Also, for the purposes herein, a "wave sensor" or "wave transducer" is any device, which senses waves either ultrasonic or electromagnetic. An electromagnetic wave sensor, for example, includes devices that sense any portion of the electromagnetic spectrum from ultraviolet down to a few hertz. The most commonly used kind of electromagnetic wave sensors include CCD and CMOS arrays for sensing visible and/or infrared, millimeter wave and microwave radar, and capacitive or electric and magnetic field monitoring sensors that rely on the dielectric constant of the object occupying a space. In this regard, reference is made to, for example, U.S. patents by Kithil et al. U.S. Pat. Nos. 5,366,241, 5,602,734, 5,691,693, 5,802,479 and 5,844,486 and Jinno et al. 5,948,031 which are included herein by reference.

3. Pattern recognition prior art

Japanese Patent 3-42337 (A) to Ueno describes a device for detecting the driving condition of a vehicle driver comprising a light emitter for irradiating the face of the

8

driver and a means for picking up the image of the driver and storing it for later analysis. Means are provided for locating the eyes of the driver and then the irises of the eyes and then determining if the driver is looking to the side or sleeping. Ueno determines the state of the eyes of the occupant rather than determining the location of the eyes relative to the other parts of the vehicle passenger compartment. Such a system can be defeated if the driver is wearing glasses, particularly sunglasses, or another optical device which obstructs a clear view of his/her eyes. Pattern recognition technologies such as neural networks are not used. The method of finding the eyes is described but not a method of adapting the system to a particular vehicle model.

U.S. Pat. No. 5,008,946 to Ando uses a complicated set of rules to isolate the eyes and mouth of a driver and uses this information to permit the driver to control the radio, for example, or other systems within the vehicle by moving his eyes and/or mouth. Ando uses natural light and illuminates only the head of the driver. He also makes no use of trainable pattern recognition systems such as neural networks, nor is there any attempt to identify the contents of the vehicle nor of their location relative to the vehicle passenger compartment. Rather, Ando is limited to control of vehicle devices by responding to motion of the driver's mouth and eyes. As with Ueno, a method of finding the eyes is described but not a method of adapting the system to a particular vehicle model.

U.S. Pat. No. 5,298,732 to Chen also concentrates in locating the eyes of the driver so as to position a light filter between a light source such as the sun or the lights of an oncoming vehicle, and the driver's eyes. Chen does not explain in detail how the eyes are located but does supply a calibration system whereby the driver can adjust the filter so that it is at the proper position relative to his or her eyes. Chen references the use of an automatic equipment for determining the location of the eyes but does not describe how this equipment works. In any event, in Chen, there is no mention of monitoring the position of the occupant, other than the eyes, determining the position of the eyes relative to the passenger compartment, or identifying any other object in the vehicle other than the driver's eyes. Also, there is no mention of the use of a trainable pattern recognition system. A method for finding the eyes is described but not a method of adapting the system to a particular vehicle model.

U.S. Pat. No. 5,305,012 to Faris also describes a system for reducing the glare from the headlights of an oncoming vehicle. Faris locates the eyes of the occupant by using two spaced apart infrared cameras using passive infrared radiation from the eyes of the driver. Faris is only interested in locating the driver's eyes relative to the sun or oncoming headlights and does not identify or monitor the occupant or locate the occupant, a rear facing child seat or any other object for that matter, relative to the passenger compartment or the airbag. Also, Faris does not use trainable pattern recognition techniques such as neural networks. Faris, in fact, does not even say how the eyes of the occupant are located but refers the reader to a book entitled Robot Vision (1991) by Berthold Horn, published by MIT Press, Cambridge, Mass. Also, Faris uses the passive infrared radiation rather than illuminating the occupant with ultrasonic or electromagnetic radiation as in some implementations of the instant invention. A method for finding the eyes of the occupant is described but not a method of adapting the system to a particular vehicle model.

The use of neural networks, or neural fuzzy systems, as the pattern recognition technology and the methods of adapting this to a particular vehicle, such as the training

US 6,397,136 B1

9

methods, is important to this invention since it makes the monitoring system robust, reliable and accurate. The resulting algorithm created by the neural network program is usually only a few hundred lines of code written in the C computer language and is in general fewer lines than when the techniques of the above patents to Ando, Chen and Faris are implemented. As a result, the resulting systems are easy to implement at a low cost making them practical for automotive applications. The cost of the ultrasonic transducers, for example, is expected to be less than about \$1 in quantities of one million per year. Similarly, the implementation of the techniques of the above-referenced patents requires expensive microprocessors while the implementation with neural networks and similar trainable pattern recognition technologies permits the use of low cost microprocessors typically costing less than about \$5 in quantities of one million per year.

The present invention uses sophisticated software that develops trainable pattern recognition algorithms such as neural networks. Usually the data is preprocessed, as discussed below, using various feature extraction techniques and the results post-processed to improve system accuracy. A non-automotive example of such a pattern recognition system using neural networks on sonar signals is discussed in two papers by Gorman, R. P. and Sejnowski, T. J. "Analysis of Hidden Units in a Layered Network Trained to Classify Sonar Targets", Neural Networks, Vol. 1. pp. 75-89, 1988, and "Learned Classification of Sonar Targets Using a Massively Parallel Network", IEEE Transactions on Acoustics, Speech, and Signal Processing, Vol. 36, No. 7, July 1988. Examples of feature extraction techniques can be found in U.S. Pat. No. 4,906,940 entitled "Process and Apparatus for the Automatic Detection and Extraction of Features in Images and Displays" to Green et al. Examples of other more advanced and efficient pattern recognition techniques can be found in U.S. Pat. No. 5,390,136 entitled "Artificial Neuron and Method of Using Same" and U.S. Pat. No. 5,517,667 entitled "Neural Network That Does Not Require Repetitive Training" to Wang, S. T. Other examples include U.S. Pat. No. 5,235,339 (Morrison et al.), U.S. Pat. No. 5,214,744 (Schweizer et al.), U.S. Pat. No. 5,181,254 (Schweizer et al.), and U.S. Pat. No. 4,881,270 (Knecht et al.). All of the references herein are included herein by reference.

4. Ultrasonics and Optics

Both laser and non-laser optical systems in general are good at determining the location of objects within the two dimensional plane of the image and a pulsed laser radar system in the scanning mode can determine the distance of each part of the image from the receiver by measuring the time of flight through range gating techniques. It is also possible to determine distance with the non-laser system by focusing, or stereographically if two spaced apart receivers are used and, in some cases, the mere location in the field of view can be used to estimate the position relative to the airbag, for example. Finally, a recently developed pulsed quantum well diode laser also provides inexpensive distance measurements as discussed in U.S. provisional patent application Ser. No. 60/114,507, filed Dec. 31, 1998, which is included herein by reference as if the entire contents were copied here.

Acoustic systems are additionally quite effective at distance measurements since the relatively low speed of sound permits simple electronic circuits to be designed and minimal microprocessor capability is required. If a coordinate system is used where the z axis is from the transducer to the occupant, acoustics are good at measuring z dimensions while simple optical systems using a single CCD or CMOS

10

arrays are good at measuring x and y dimensions. The combination of acoustics and optics, therefore, permits all three measurements to be made from one location with low cost components as discussed in commonly assigned U.S. Pat. Nos. 5,845,000 and 5,835,613 cross-referenced above.

One example of a system using these ideas is an optical system which floods the passenger seat with infrared light coupled with a lens and a receiver array, e.g., CCD or CMOS array, which receives and displays the reflected light and an analog to digital converter (ADC) which digitizes the output of the CCD or CMOS and feeds it to an Artificial Neural Network (ANN) or other pattern recognition system for analysis. This system uses an ultrasonic transmitter and receiver for measuring the distances to the objects located in the passenger seat. The receiving, transducer feeds its data into an ADC and from there the converted data is directed into the ANN. The same ANN can be used for both systems thereby providing full three-dimensional data for the ANN to analyze. This system, using low cost components, will permit accurate identification and distance measurements not possible by either system acting alone. If a phased array system is added to the acoustic part of the system, the optical part can determine the location of the driver's ears, for example, and the phased array can direct a narrow beam to the location and determine the distance to the occupant's ears.

Although the use of ultrasound for distance measurement has many advantages, it also has some drawbacks. First, the speed of sound limits the rate at which the position of the occupant can be updated to approximately 10 milliseconds, which though sufficient for most cases, is marginal if the position of the occupant is to be tracked during a vehicle crash. Second, ultrasound waves are diffracted by changes in air density that can occur when the heater or air conditioner is operated or when there is a high-speed flow of air past the transducer. Third, the resolution of ultrasound is limited by its wavelength and by the transducers, which are high Q tuned devices. Typically, the resolution of ultrasound is on the order of about 2 to 3 inches. Finally, the fields from ultrasonic transducers are difficult to control so that reflections from unwanted objects or surfaces add noise to the data.

Ultrasonics alone can be used in several configurations for monitoring the interior of a passenger compartment of an automobile as described in the above-referenced patents and patent applications and in particular in U.S. Pat. No. 5,943,295. Using the teachings of this invention, the optimum number and location of the ultrasonic and/or optical transducers can be determined as part of the adaptation process for a particular vehicle model.

In the cases of the instant invention, as discussed in more detail below, regardless of the number of transducers used, a trained pattern recognition system, as defined above, is used to identify and classify, and in some cases to locate, the illuminated object and its constituent parts.

5. Applications

The applications for this technology are numerous as described in the patents and patent applications listed above. However, the main focus of the instant invention is the process and resulting apparatus of adapting the system in the patents and patent applications referenced above for the detection of the presence of an occupied child seat in the rear facing position or an out-of-position occupant and the detection of an occupant in a normal seating position. The system is designed so that in the former two cases, deployment of the occupant protection apparatus (airbag) may be controlled and possibly suppressed and in the latter, it will be controlled and enabled.

US 6,397,136 B1

11

One preferred implementation of a first generation occupant sensing system, which is adapted to various vehicle models using the teachings presented herein, is an ultrasonic occupant position sensor. This system uses an Artificial Neural Network (ANN) to recognize patterns that it has been trained to identify as either airbag enable or airbag disable conditions. The pattern is obtained from four ultrasonic transducers that cover the front passenger seating area. This pattern consists of the ultrasonic echoes bouncing off of the objects in the passenger seat area. The signal from each of the four transducers consists of the electrical image of the return echoes, which is processed by the electronics. The electronic processing comprises amplification, logarithmic compression, rectification, and demodulation (band pass filtering), followed by discretization (sampling) and digitization of the signal. The only software processing required, before this signal can be fed into the artificial neural network, is normalization (i.e., mapping the input to numbers between 0 and 1). Although this is a fair amount of processing, the resulting signal is still considered "raw", because all information is treated equally.

OBJECTS AND SUMMARY OF THE INVENTION

In general, it is an object of the present invention to provide a new and improved system for identifying the presence, position and/or orientation of an object in a vehicle.

It is another broad object of the present invention to provide a system for accurately detecting the presence of an occupied rear-facing child seat in order to prevent an occupant protection apparatus, such as an airbag, from deploying, when the airbag would impact against the rear-facing child seat if deployed.

It is yet another broad object of the present invention to provide a system for accurately detecting the presence of an out-of-position occupant in order to prevent one or more deployable occupant protection apparatus such as airbags from deploying when the airbag(s) would impact against the head or chest of the occupant during its initial deployment phase causing injury or possible death to the occupant.

This invention is a system designed to identify, locate and monitor occupants, including their parts, and other objects in the passenger compartment and in particular an occupied child seat in the rear facing position or an out-of-position occupant, by illuminating the contents of the vehicle with ultrasonic or electromagnetic radiation, for example, by transmitting radiation waves from a wave generating apparatus into a space above the seat, and receiving radiation modified by passing through the space above the seat using two or more transducers properly located in the vehicle passenger compartment, in specific predetermined optimum location. More particularly, this invention relates to a system including a plurality of transducers appropriately located and mounted and which analyze the received radiation from any object which modifies the waves, in order to achieve an accuracy of recognition heretofore not possible. Outputs from the receivers are analyzed by appropriate computational means employing trained pattern recognition technologies, to classify, identify and/or locate the contents, and/or determine the orientation of, for example, a rear facing child seat. In general, the information obtained by the identification and monitoring system is used to affect the operation of some other system, component or device in the vehicle and particularly the passenger and/or driver airbag systems airbag, which may include a front airbag, a side

12

airbag, a knee bolster, or combinations of the same. However, the information obtained can be used for controlling or affecting the operation of a multitude of other vehicle systems.

When the vehicle interior monitoring system in accordance with the invention is installed in the passenger compartment of an automotive vehicle equipped with a occupant protection apparatus, such as an inflatable airbag, and the vehicle is subjected to a crash of sufficient severity that the crash sensor has determined that the protection apparatus is to be deployed, the system has determined (usually prior to the deployment) whether a child placed in the rear facing position in the child seat is present and if so, a signal has been sent to the control circuitry that the airbag should be controlled and most likely disabled and not deployed in the crash. It must be understood though that instead of suppressing deployment, it is possible that the deployment may be controlled so that it might provide some meaningful protection for the occupied rear-facing child seat. The system developed using the teachings of this invention also determines the position of the vehicle occupant relative to the airbag and controls and possibly disables deployment of the airbag if the occupant is positioned so that he/she is likely to be injured by the deployment of the airbag. As before, the deployment is not necessarily disabled but may be controlled to provide protection for the out-of-position occupant.

Principle objects and advantages of the methods in accordance with the invention are:

1. To provide a reliable system for recognizing the presence of a rear-facing child seat on a particular seat of a motor vehicle.
2. To provide a reliable system for recognizing the presence of a human being on a particular seat of a motor vehicle.
3. To provide a reliable system for determining the position, velocity or size of an occupant in a motor vehicle.
4. To provide a reliable system for determining in a timely manner that an occupant is out-of-position, or will become out-of-position, and likely to be injured by a deploying airbag.
5. To provide a system in which transducers are located within the passenger compartment at specific locations such that a high reliability of classification of objects and their position is obtained from the signals generated by the transducers.
6. To provide a system including a variety of transducers such as seatbelt payout sensors, seatbelt buckle sensors, seat position sensors, seatback position sensors, and weight sensors and which is adapted so as to constitute a highly reliable occupant presence and position system when used in combination with electromagnetic, ultrasonic or other radiation sensors.

Accordingly, in a vehicle including system for determining the occupancy state of a seat therein in accordance with the invention, the system comprises a plurality of transducers arranged in the vehicle, each transducers providing data relating to the occupancy state of the seat, and processor means coupled to the transducers for receiving the data from the transducers and processing the data to obtain an output indicative of the current occupancy state of the seat. The processor means comprise an algorithm created from a plurality of data sets, each representing a different occupancy state of the seat and being formed from data from the transducers while the seat is in that occupancy state. The algorithm produces the output indicative of the current

US 6,397,136 B1

13

occupancy state of the seat upon inputting a data set representing the current occupancy state of the seat and being formed from data from the transducers. The algorithm may be a pattern recognition algorithm or neural network algorithm generated by a neural network algorithm-generating program.

In accordance with some embodiments of the invention, the processor means are arranged to accept only a separate stream of data from each transducer such that the stream of data from each transducer is passed to the processor means without combining with another stream of data. Further, the processor means may be arranged to process each separate stream of data independent of the processing of the other streams of data.

It is an important feature of the invention that the transducers may be selected from a wide variety of different sensors, all of which are affected by the occupancy state of the seat. That is, different combinations of known sensors can be utilized in the many variations of the invention. For example, the sensors used in the invention may include a weight sensor arranged in the seat, a reclining angle detecting sensor for detecting a tilt angle of the seat between a back portion of the seat and a seat portion of the seat, a seat position sensor for detecting the position of the seat relative to a fixed reference point in the vehicle, a heartbeat sensor for sensing a heartbeat of an occupying item of the seat, a capacitive sensor, a seat belt buckle sensor, a seatbelt payout sensor, an infrared sensor, an inductive sensor, a motion sensor and a radar sensor. The same type of sensor could also be used, preferably situated in a different location, but possibly in the same location for redundancy purposes. For example, the system may include a plurality of weight sensors, each measuring the weight applied onto the seat at a different location. Such weight sensors may include a weight sensor, such as a strain gage, arranged to measure displacement of a surface of a seat portion of the seat and/or a strain, force or pressure gage arranged to measure displacement of the entire seat. In the latter case, the seat includes a support structure for supporting the seat above a floor of a passenger compartment of the vehicle whereby the strain gage can be attached to the support structure.

In some embodiments, the transducers include a plurality of electromagnetic wave sensors capable of receiving waves at least from a space above the seat, each electromagnetic wave sensor being arranged at a different location.

In other embodiments, the transducers include at least two ultrasonic sensors capable of receiving waves at least from a space above the seat, each ultrasonic sensor being arranged at a different location. For example, one sensor is arranged on a ceiling of the vehicle and the other is arranged at a different location in the vehicle, preferably so that an axis connecting the sensors is substantially parallel to a second axis traversing a volume in the vehicle above the seat. The second sensor may be arranged on a dashboard or instrument panel of the vehicle. A third ultrasonic sensor can be arranged on an interior side surface of the passenger compartment while a fourth can be arranged on or adjacent an interior side surface of the passenger compartment. The ultrasonic sensors are capable of transmitting waves at least into the space above the seat. Further, the ultrasonic sensors are preferably aimed such that the ultrasonic fields generated thereby cover a substantial portion of the volume surrounding the seat. Horns or grills may be provided for adjusting the transducer field angles of the ultrasonic sensors to reduce reflections off of fixed surfaces within the vehicle or otherwise control the shape of the ultrasonic field.

The actual location of the ultrasonic sensors can be determined by placing a significant number of ultrasonic

14

sensors in the vehicle and removing those sensors which prove analytically to be redundant.

The ultrasonic sensors can have different transmitting and receiving frequencies and be arranged in the vehicle such that sensors having adjacent transmitting and receiving frequencies are not within a direct ultrasonic field of each other.

Once the occupancy state of the seat (or seats) in the vehicle is known, this information can be used to control or affect the operation of a significant number of vehicular systems, components and devices. That is, the systems, components and devices in the vehicle would be controlled in consideration of the occupancy of the seat(s) in the vehicle, possibly to optimize operation of the same. Thus, the vehicle includes control means coupled to the processor means for controlling a component or device in the vehicle in consideration of the output indicative of the current occupancy state of the seat obtained from the processor means. The component or device can be an airbag system including at least one deployable airbag whereby the deployment of the airbag is suppressed, e.g., if the seat is occupied by a rear-facing child seat, or otherwise the parameters of the deployment are controlled.

In another embodiment of the invention, the system for determining the occupancy state of a seat in a vehicle includes a plurality of transducers arranged in the vehicle, each providing data relating to the occupancy state of the seat, and processor means coupled to the transducers for receiving only a separate stream of data from each transducer (such that the stream of data from each transducer is passed to the processor means without combining with another stream of data) and processing the streams of data to obtain an output indicative of the current occupancy state of the seat. The processor means comprise an algorithm created from a plurality of data sets, each representing a different occupancy state of the seat and being formed from separate streams of data, each only from one transducer, while the seat is in that occupancy state. The algorithm produces the output indicative of the current occupancy state of the seat upon inputting a data set representing the current occupancy state of the seat and being formed from separate streams of data, each only from one transducer. The processor means preferably process each separate stream of data independent of the processing of the other streams of data.

In yet another embodiment of the invention, the system for determining the occupancy state of a seat in a vehicle includes a plurality of transducers including at least two wave-receiving transducers arranged in the vehicle, each providing data relating to the occupancy state of the seat. One wave-receiving transducer is arranged on or adjacent to a ceiling of the vehicle and a second wave-receiving transducer is arranged at a different location in the vehicle such that an axis connecting these wave-receiving transducers is substantially parallel to a longitudinal axis of the vehicle, substantially parallel to a transverse axis of the vehicle or passes through a volume above the seat. A processor is coupled to the transducers for receiving data from the transducers and processing the data to obtain an output indicative of the current occupancy state of the seat. The processor comprises an algorithm which produces the output indicative of the current occupancy state of the seat upon inputting a data set representing the current occupancy state of the seat and being formed from data from the transducers.

In still another embodiment of the invention, the system includes a plurality of transducers arranged in the vehicle, each providing data relating to the occupancy state of the

US 6,397,136 B1

15

seat, and which include a wave-receiving transducer and a non-wave-receiving transducer. The system also includes processor means coupled to the transducers for receiving the data from the transducers and processing the data to obtain an output indicative of the current occupancy state of the seat. The processor means comprising an algorithm created from a plurality of data sets, each representing a different occupancy state of the seat and being formed from data from the transducers while the seat is in that occupancy state. The algorithm produces the output indicative of the current occupancy state of the seat upon inputting a data set representing the current occupancy state of the seat and being formed from data from the transducers.

These and other objects and advantages will become apparent from the following description of the preferred embodiments of the vehicle identification and monitoring system of this invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The following drawings are illustrative of embodiments of the system developed or adapted using the teachings of this invention and are not meant to limit the scope of the invention as encompassed by the claims. In particular, the illustrations below are limited to the monitoring of the front passenger seat for the purpose of describing the system. Naturally, the invention applies as well to adapting the system to the other seating positions in the vehicle and particularly to the driver position.

FIG. 1 shows a seated-state detecting unit developed in accordance with the present invention and the connections between ultrasonic or electromagnetic sensors, a weight sensor, a reclining angle detecting sensor, a seat track position detecting sensor, a heartbeat sensor, a motion sensor, a neural network circuit, and an airbag system installed within a vehicle compartment;

FIG. 2 is a perspective view of a vehicle containing two adult occupants on the front seat with the vehicle shown in phantom illustrating one preferred location of the ultrasonic transducers placed according to the methods taught in this invention.

FIG. 3 is a view as in FIG. 2 with the passenger occupant replaced by a child in a forward facing child seat.

FIG. 4 is a view as in FIG. 2 with the passenger occupant replaced by a child in a rearward facing child seat.

FIG. 5 is a view as in FIG. 2 with the passenger occupant replaced by an infant in an infant seat.

FIG. 6 is a diagram illustrating the interaction of two ultrasonic sensors and how this interaction is used to locate a circle in space.

FIG. 7 is a view as in FIG. 2 with the occupants removed illustrating the location of two circles in space and how they intersect the volumes characteristic of a rear facing child seat and a larger occupant.

FIG. 8 illustrates a preferred mounting location of a three-transducer system.

FIG. 9 illustrates a preferred mounting location of a four-transducer system.

FIG. 10 is a plot showing the target volume discrimination for two transducers.

FIG. 11 illustrates a preferred mounting location of a eight-transducer system.

FIG. 12 is a chart of four typical raw signals which are combined to constitute a vector.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

System Adaptation involves the process by which the hardware configuration and the software algorithms are

16

determined for a particular vehicle. Each vehicle model or platform will most likely have a different hardware configuration and different algorithms. Some of the various aspects that make up this process are as follows:

- 5 The determination of the mounting location and aiming of the transducers.
- The determination of the transducer field angles
- The use of a neural network algorithm generating program such as commercially available from NeuralWare to help generate the algorithms.
- 10 The process of the collection of data in the vehicle for neural network training purposes.
- The method of automatic movement of the vehicle seats etc. while data is collected
- The determination of the quantity of data to acquire and the setups needed to achieve a high system accuracy, typically several hundred thousand vectors.
- The collection of data in the presence of varying environmental conditions such as with thermal gradients.
- The photographing of each data setup.
- 20 The makeup of the different databases and the use of three different databases.
- The method by which the data is biased to give higher probabilities for forward facing humans.
- 25 The automatic recording of the vehicle setup including seat, seat back, headrest, window, visor, armrest positions to help insure data integrity.
- The use of a daily setup to validate that the transducer configuration has not changed.
- 30 The method by which bad data is culled from the database.
- The inclusion of the Fourier transforms and other pre-processors of the data in the training process.
- The use of multiple network levels, for example, for categorization and position.
- 35 The use of multiple networks in parallel.
- The use of post processing filters and the particularities of these filters.
- The addition of fuzzy logic or other human intelligence based rules.
- 40 The method by which vector errors are corrected using, for example, a neural network.
- The use of neural works as the pattern recognition algorithm generating system.
- The use of back propagation neural networks from training.
- 45 The use of vector normalization.
- The use of feature extraction techniques including:
 - The number of data points prior to a peak.
 - The normalization factor.
 - The total number of peaks.
 - The vector mean or variance.
- 50 The use of other computational intelligence systems such as the genetic algorithms
- The use the data screening techniques.
- The techniques used to develop a stable network including the concepts of a old and a new network.
- The time spent or the number of iterations spent in, and method of, arriving at a stable network.
- The technique where a small amount of data is collected first such as 16 sheets followed by a complete data collection sequence.
- 60 The process of adapting the system to the vehicle begins with a survey of the vehicle model. Any existing sensors, such as seat position sensors, seat back sensors, etc., are immediate candidates for inclusion into the system. Input from the customer will determine what types of sensors would be acceptable for the final system. These sensors can include: seat structure mounted weight sensors, pad type

US 6,397,136 B1

17

weight sensors, pressure type weight sensors, seat fore and aft position sensors, seat vertical position sensors, seat angular position sensors, seat back position sensors, headrest position sensors, ultrasonic occupant sensors, optical occupant sensors, capacitive sensors, inductive sensors, radar sensors, vehicle velocity and acceleration sensors, brake pressure, seatbelt force, payout and buckle sensors. etc. A candidate array of sensors is then chosen and mounted onto the vehicle.

The vehicle is also instrumented so that data input by humans is minimized. Thus, the positions of the various components in the vehicle such as the seats, windows, sun visor, armrest, etc. are automatically recorded. Also, the position of the occupant while data is being taken is also absolutely recorded through a variety of techniques such as direct ultrasonic ranging sensors, optical ranging sensors, radar ranging sensors, optical tracking sensors etc. Cameras are also installed to take a picture of the setup to correspond to each vector of data collected or at some other appropriate frequency.

A standard set of vehicle setups is chosen for initial trial data collection purposes. Typically, the initial trial will consist of between 20,000 and 100,000 setups.

Initial digital data collection now proceeds for the trial setup matrix. The data is collected from the transducers, digitized and combined to form to a vector of input data for analysis by a neural network program. This analysis should yield a training accuracy of nearly 100%. If this is not achieved, then additional sensors are added to the system or the configuration changed and the data collection and analysis repeated.

In addition to a variety of seating states for objects in the passenger compartment, the trial database will also include environmental effects such as thermal gradients caused by heat lamps and the operation of the air conditioner and heater. A sample of such a matrix is presented in Appendix 1. After the neural network has been trained on the trial database, the trial database will be scanned for vectors that yield erroneous results (which would likely be considered bad data). A study of those vectors along with vectors from associated in time cases are compared with the photographs to determine whether there is erroneous data present. If so, an attempt is made to determine the cause of the erroneous data. If the cause can be found, for example if a voltage spike on the power line corrupted the data, then the vector will be removed from the database and an attempt is made to correct the data collection process so as to remove such disturbances.

At this time, some of the sensors may be eliminated from the sensor matrix. This can be determined during the neural network analysis by selectively eliminating sensor data from the analysis to see what the effect if any results. Caution should be exercised here, however, since once the sensors have been initially installed in the vehicle, it requires little additional expense to use all of the installed sensors in future data collection and analysis.

The neural network that has been developed in this first phase is used during the data collection in the next phases as an instantaneous check on the integrity of the new vectors being collected. Occasionally, a voltage spike or other environmental disturbance will momentarily effect the data from some transducers. It is important to capture this event to first eliminate that data from the database and second to isolate the cause of the erroneous data.

The next set of data to be collected is the training database. This will be the largest database initially collected and will cover such setups as listed, for example, in Appen-

18

dix 1. The training database, which may contain 500,000 or more vectors, will be used to begin training of the neural network. While this is taking place additional data will be collected according to Appendix 1 of the independent and validation databases. The training database has been selected so that it uniformly covers all seated states that are known to be likely to occur in the vehicle. The independent database may be similar in makeup to the training database or it may evolve to more closely conform to the occupancy state distribution of the validation database. During the neural network training, the independent database is used to check the accuracy of the neural network and to reject a candidate neural network design if its accuracy, measured against the independent database, is less than that of a previous network architecture.

Although the independent database is not actually used in the training of the neural network, nevertheless, it has been found that it significantly influences the network structure. Therefore, a third database, the validation or real world database, is used as a final accuracy check of the chosen system. It is the accuracy against this validation database that is considered to be the system accuracy. The validation database is composed of vectors taken from setups which closely correlate with vehicle occupancy in real cars on the roadway. Initially the training database is the largest of the three databases. As time and resources permit the independent database, which perhaps starts out with 100,000 vectors, will continue to grow until it becomes approximately the same size as the training database. The validation database, on the other hand, will typically start out with as few as 50,000 vectors. However, as the hardware configuration is frozen, the validation database will continuously grow until, in some cases, it actually becomes larger than the training database. This is because near the end of the program, vehicles will be operating on highways and data will be collected in real world situations. If in the real world tests, system failures are discovered this can lead to additional data being taken for both the training and independent databases as well as the validation database.

Once a network has been trained using all of the available data from all of the transducers, it is expected that the accuracy of the network will be very close to 100%. It is usually not practical to use all of the transducers that have been used in the training of the system for final installation in real production vehicle models. This is primarily due to cost and complexity considerations. Usually the automobile manufacturer will have an idea of how many sensors would be acceptable for installation in a production vehicle. For example, the data may have been collected using 20 different transducers but the automobile manufacturer may restrict the final selection to 6 transducers. The next process, therefore, is to gradually eliminate sensors to determine what is the best combination of six sensors, for example, to achieve the highest system accuracy. Ideally, a series of networks would be trained using all combinations of six sensors from the 20 available. The activity would require a prohibitively long time. Certain constraints can be factored into the system from the beginning to start the pruning process. For example, it would probably not make sense to have both optical and ultrasonic sensors present in the same system since it would complicate the electronics. In fact, the automobile manufacturer may have decided initially that an optical system would be too expensive and therefore would not be considered. The inclusion of optical sensors, therefore, serves as a way of determining the loss in accuracy as a function of cost. Various constraints, therefore, usually allow the immediate elimination of a significant

US 6,397,136 B1

19

number of the initial group of sensors. This elimination and the training on the remaining sensors provides the resulting accuracy loss that results.

The next step is to remove each of the sensors one at a time and determine which sensor has the least effect on the system accuracy. This process is then repeated until the total number of sensors has been pruned down to the number desired by the customer. At this point, the process is reversed to add in one at a time those sensors that were removed at previous stages. It has been found, for example, that a sensor that appears to be unimportant during the early pruning process can become very important later on. Such a sensor may add a small amount of information due to the presence of various other sensors. Whereas the various other sensors, however, may yield less information than still other sensors and, therefore may have been removed during the pruning process. Reintroducing the sensor that was eliminated early in the cycle therefore can have a significant effect and can change the final choice of sensors to make up the system.

The above method of reducing the number of sensors that make up the system is but one of a variety approaches which have applicability in different situations. In some cases a Monte Carlo or other statistical approach is warranted, whereas in other cases a design of experiments approach has proven to be the most successful. In many cases, an operator conducting this activity becomes skilled and after a while knows intuitively what set of sensors is most likely to yield the best results. During the process it is not uncommon to run multiple cases on different computers simultaneously. Also, during this process, a database of the cost of accuracy is generated. The automobile manufacturer, for example, may desire to have the total of 6 transducers in the final system, however, when shown the fact that the addition of one or two additional sensors substantially increases the accuracy of the system, the manufacturer may change his mind. Similarly, the initial number of sensors selected may be 6 but the analysis could show that 4 sensors give substantially the same accuracy as 6 and therefore the other 2 can be eliminated at a cost saving.

While the pruning process is occurring, the vehicle is subjected to a variety of road tests and would be subjected to presentations to the customer. The road tests are tests that are run at different locations than where the fundamental training took place. It has been found that unexpected environmental factors can influence the performance of the system and therefore these tests can provide critical information. The system, therefore, which is installed in the test vehicle should have the capability of recording system failures. This recording includes the output of all of the sensors on the vehicle as well as a photograph of the vehicle setup that caused the error. This data is later analyzed to determine whether the training, independent or validation setups need to be modified and/or whether the sensors or positions of the sensors require modification.

Once the final set of sensors has been chosen, the vehicle is again subjected to real world testing on highways and at customer demonstrations. Once again any failures are recorded. In this case, however, since the total number of sensors in the system is probably substantially less than the initial set of sensors, certain failures are to be expected. All such failures, if expected, are reviewed carefully with the customer to be sure that the customer recognizes the system failure modes and is prepared to accept the system with those failure modes.

The system described so far has been based on the use of a single neural network. It is frequently necessary to use multiple neural networks or other pattern recognition sys-

20

tems. For example, for determining the occupancy state of a vehicle seat there are really two requirements. The first requirement is to establish what is occupying the seat and the second requirement is to establish where that object is located. Generally, a great deal of time, typically many seconds, is available for determining whether a forward facing human or an occupied or unoccupied rear facing child seat, for example, occupies the vehicle seat. On the other hand, if the driver of the car is trying to avoid an accident and is engaged in panic braking, the position of an unbelted occupant can be changing rapidly as he or she is moving toward the airbag. Thus, the problem of determining the location of an occupant is time critical. Typically, the position of the occupant in such situations must be determined in less than 20 milliseconds. There is no reason for the system to have to determine that a forward facing human being is in the seat while simultaneously determining where that forward facing human being is. The system already knows that the forward facing human being is present and therefore all of the resources can be used to determine the occupant's position. Thus, in this situation a dual level or modular neural network can be advantageously used. The first level determines the occupancy of the vehicle seat and the second level determines the position of that occupant. In some rare situations, it has been demonstrated that multiple neural networks used in parallel can provide some benefit. This will be discussed in more detail below.

The data that is fed to the pattern recognition system typically will usually not be the raw vectors of data as captured and digitized from the various transducers. Typically, a substantial amount of preprocessing of the data is undertaken to extract the important information from the data that is fed to the neural network. This is especially true in optical systems and where the quantity of data obtained, if all were used by the neural network, would require very expensive processors. The techniques of preprocessing data will not be described in detail here. However, the preprocessing techniques influence the neural network structure in many ways. For example, the preprocessing used to determine what is occupying a vehicle seat is typically quite different from the preprocessing used to determine the location of that occupant. Some particular preprocessing concepts will be discussed in more detail below.

Once the pattern recognition system has been applied to the preprocessed data, one or more decisions are available as output. The output from the pattern recognition system is usually based on a snapshot of the output of the various transducers. Thus, it represents one epoch or time period. The accuracy of such a decision can usually be substantially improved if previous decisions from the pattern recognition system are also considered. In the simplest form, which is typically used for the occupancy identification stage, the results of many decisions are averaged together and the resulting averaged decision is chosen as the correct decision. Once again, however, the situation is quite different for dynamic out-of-position. The position of the occupant must be known at that particular epoch and cannot be averaged with his previous position. On the other hand, there is information in the previous positions that can be used to improve the accuracy of the current decision. For example, if the new decision says that the occupant has moved six inches since the previous decision, and, from physics, it is known that this could not possibly take place, than a better estimate of the current occupant position can be made by extrapolating from earlier positions. Alternately, an occupancy position versus time curve can be fitted using a variety of techniques such as the least squares regression method, to

US 6,397,136 B1

21

the data from previous 10 epochs, for example. This same type of analysis could also be applied to the vector itself rather than to the final decision thereby correcting the data prior to its being entered into the pattern recognition system.

A pattern recognition system, such as a neural network, can sometimes make totally irrational decisions. This typically happens when the pattern recognition system is presented with a data set or vector that is unlike any vector that has been in its training set. The variety of seating states of a vehicle is unlimited. Every attempt is made to select from that unlimited universe a set of representative cases. Nevertheless, there will always be cases that are significantly different from any that have been previously presented to the neural network. The final step, therefore, to adapting a system to a vehicle, is to add a measure of human intelligence. Sometimes this goes under the heading of fuzzy logic and the resulting system has been termed in some cases a neural fuzzy system. In some cases, this takes the form of an observer studying failures of the system and coming up with rules and that say, for example, that if sensor A perhaps in combination with another sensor produces values in this range than the system should be programmed to override the pattern recognition decision and substitute therefor a human decision.

An example of this appears in R. Scorcioni, K. Ng, M. M. Trivedi, N. Lassiter; "MoNiF: A Modular Neuro-Fuzzy Controller for Race Car Navigation"; In Proceedings of the 1997 *IEEE Symposium on Computational Intelligence and Robotics Applications*, Monterey, Calif., USA July 1997 and describes the case of where an automobile was designed for autonomous operation and trained with a neural network, in one case, and a neural fuzzy system in another case. As long as both vehicles operated on familiar roads both vehicles performed satisfactorily. However, when placed on an unfamiliar road, the neural network vehicle failed while the neural fuzzy vehicle continue to operate successfully. Naturally, if the neural network vehicle had been trained on the unfamiliar road, it might very well have operated successfully. Nevertheless, the critical failure mode of neural networks that most concerns people is this uncertainty as to what a neural network will do when confronted with an unknown state.

One aspect, therefore, of adding human intelligence to the system, is to ferret out those situations where the system is likely to fail. Unfortunately, in the current state-of-the-art, this is largely a trial and error activity. One example is that if the range of certain parts of vector falls outside of the range experienced during training, the system defaults to a particular state. In the case of suppressing deployment of one or more airbags, or other occupant protection apparatus, this case would be to enable airbag deployment even if the pattern recognition system calls for its being disabled.

The foregoing description is applicable to the systems described in the following drawings and the connection between the foregoing description and the systems described below will be explained below. However, it should be appreciated that the systems shown in the drawings do not limit the applicability of the methods or apparatus described above.

Referring to the accompanying drawings wherein like reference numbers designate the same or similar elements, FIG. 1 shows a passenger seat 1 to which an adjustment apparatus including a seated-state detecting system developed according to the present invention may be applied. The seat 1 includes a horizontally situated bottom seat portion 2 and a vertically oriented back portion 3. The seat portion 2 is provided with weight measuring means, i.e., one or more

22

weight sensors 6 and 7, that determine the weight of the object occupying the seat, if any. The coupled portion between the seated portion 2 and the back portion 3 (also referred to as the seatback) is provided with a reclining angle detecting sensor 9, which detects the tilted angle of the back portion 3 relative to the seat portion 2. The seat portion 2 is provided with a seat track position-detecting sensor 10. The seat track position detecting sensor 10 fulfills a role of detecting the quantity of movement of the seat 1 which is moved from a back reference position, indicated by the dotted chain line. Embedded within the seatback 3 is a heartbeat sensor 31 and a motion sensor 33. Attached to the headliner of the vehicle is a capacitance sensor 32. The seat 1 may be the driver seat, the front passenger seat or any other seat in a motor vehicle as well as other seats in transportation vehicles or seats in non-transportation applications.

Motion sensor 33 can be a discrete sensor that detects relative motion in the passenger compartment of the vehicle. Such sensors are frequently based on ultrasonics and can measure a change in the ultrasonic pattern that occurs over a short time period. Alternately, the subtracting of one position vector from a previous position vector to achieve a differential position vector can detect motion. For the purposes herein, a motion sensor will be used to mean either a particular device that is designed to detect motion for the creation of a special vector based on vector differences.

The weight measuring means, such as the sensors 6 and 7, are associated with the seat, and can be mounted into or below the seat portion 2 or on the seat structure, for example, for measuring the weight applied onto the seat. The weight may be zero if no occupying item is present. Sensors 6 and 7 may represent a plurality of different sensors which measure the weight applied onto the seat at different portions thereof or for redundancy purposes, for example, such as by means of an airbag or bladder 5 in the seat portion 2. The bladder 5 may have one or more compartments. Such sensors may be in the form of strain, force or pressure sensors which measure the force or pressure on the seat portion 2 or seat back 3, displacement measuring sensors which measure the displacement of the seat surface or the entire seat 1 such as through the use of strain gages mounted on the seat structural members, such as 7, or other appropriate locations, or systems which convert displacement into a pressure wherein a pressure sensor can be used as a measure of weight.

An ultrasonic or optical sensor system 12 is mounted on the upper portion of the front pillar, A-Pillar, of the vehicle and a similar sensor system 11 is mounted on the upper portion of the intermediate pillar, B-Pillar. The outputs of the transducers 11 and 12 are input to a band pass filter 20 through a multiplex circuit 19 which is switched in synchronization with a timing signal from the ultrasonic sensor drive circuit 18, and then is amplified by an amplifier 21. The band pass filter 20 removes a low frequency wave component from the output signal and also removes some of the noise. The envelope wave signal is input to an analog/digital converter (ADC) 22 and digitized as measured data. The measured data is input to a processing circuit 23, which is controlled by the timing signal which is in turn output from the sensor drive circuit 18.

Each of the measured data is input to a normalization circuit 24 and normalized. The normalized measured data is input to the neural network (circuit) 25 as wave data.

The output of the weight sensor(s) 6 and 7 is amplified by an amplifier 26 coupled to the weight sensor(s) 6 and 7 and the amplified output is input to an analog/digital converter and then directed to the neural network 25 of the processor means.

US 6,397,136 B1

23

The reclining angle detecting sensor 9 and the seat track position-detecting sensor 10 are connected to appropriate electronic circuits. For example, a constant-current can be supplied from a constant-current circuit to the reclining angle detecting sensor 9, and the reclining angle detecting sensor 9 converts a change in the resistance value on the tilt of the back portion 3 to a specific voltage. This output voltage is input to an analog/digital converter 28 as angle data, i.e., representative of the angle between the back portion 3 and the seat portion 2. Similarly, a constant current can be supplied from a constant-current circuit to the seat track position detecting sensor 10 and the seat track position detecting sensor 10 converts a change in the resistance value based on the track position of the seat portion 2 to a specific voltage. This output voltage is input to an analog/digital converter 29 as seat track data. Thus, the outputs of the reclining angle-detecting sensor 9 and the seat track position-detecting sensor 10 are input to the analog/digital converters (ADC) 28 and 29, respectively. Each digital data value from the ADCs 28, 29 is input to the neural network 25. A more detailed description of this and similar systems can be found in the above-referenced patents and patent applications assigned to the current assignee, all of which are included herein by reference. The system described above is one example of many systems that can be designed using the teachings of this invention for detecting the occupancy state of the seat of a vehicle.

The neural network 25 is directly connected to the ADCs 28 and 29, the ADC associated with amplifier 25 and the normalization circuit 24. As such, information from each of the sensors in the system (a stream of data) is passed directly to the neural network 25 for processing thereby. The streams of data from the sensors are not combined prior to the neural network 25 and the neural network is designed to accept the separate streams of data (e.g., at least a part of the data at each input node) and process them to provide an output indicative of the current occupancy state of the seat. The neural network 25 thus includes or incorporates an algorithm derived by training in the manners discussed above and below. Once the current occupancy state of the seat is determined, it is possible to control vehicular components or systems, such as the airbag system, in consideration of the current occupancy state of the seat.

A section of the passenger compartment of an automobile is shown generally as 100 in FIG. 2. A driver 101 of a vehicle sits on a seat 102 behind a steering wheel, not shown, and an adult passenger 103 sits on seat 104 on the passenger side. Two transmitter and receiver assemblies 110 and 111, also referred to herein as transducers, are positioned in the passenger compartment 100, one transducer 110 is arranged on the headliner adjacent or in proximity to the dome light and the other transducer 111 is arranged on the center of the top of the dashboard or instrument panel of the vehicle. The methodology leading to the placement of these transducers is central to the instant invention as explained in detail below. In this situation, the system developed in accordance with this invention will reliably detect that an occupant is sitting on seat 104 and deployment of the airbag is enabled in the event that the vehicle experiences a crash. Transducers 110, 111 are placed with their separation axis parallel to the separation axis of the head, shoulder and rear facing child seat volumes of occupants of an automotive passenger seat and in view of this specific positioning, are capable of distinguishing the different configurations. In addition to the ultrasonic transducers 110, 111, weight-measuring sensors 210, 211, 212, 214 and 215 are also present. These weight sensors may be of a variety of technologies including, as

24

illustrated here, strain-measuring transducers attached to the vehicle seat support structure as described in more detail in co-pending U.S. patent application Ser. No. 08/920,822. Naturally other weight systems can be utilized including systems that measure the deflection of, or pressure on, the seat cushion. The weight sensors described here are meant to be illustrative of the general class of weight sensors and not an exhaustive list of methods of measuring occupant weight.

In FIG. 3, a forward facing child seat 120 containing a child 121 replaces the adult passenger 103 as shown in FIG. 2. In this case, it is usually required that the airbag not be disabled in the event of an accident. However, in the event that the same child seat is placed in the rearward facing position as shown in FIG. 4, then the airbag is usually required to be disabled since deployment of the airbag in a crash can seriously injure or even kill the child. Furthermore, as illustrated in FIG. 5, if an infant 131 in an infant carrier 130 is positioned in the rear facing position of the passenger seat, the airbag should be disabled for the reasons discussed above. Instead of disabling deployment of the airbag, the deployment could be controlled to provide protection for the child, e.g., to reduce the force of the deployment of the airbag. It should be noted that the disabling or enabling of the passenger airbag relative to the item on the passenger seat may be tailored to the specific application. For example, in some embodiments, with certain forward facing child seats, it may in fact be desirable to disable the airbag and in other cases to deploy a depowered airbag. The selection of when to disable, depower or enable the airbag, as a function of the item in the passenger seat and its location, is made during the programming or training stage of the sensor system and, in most cases, the criteria set forth above will be applicable, i.e., enabling airbag deployment for a forward facing child seat and an adult in a proper seating position and disabling airbag deployment for a rearward facing child seat and infant and for any occupant who is out-of-position and in close proximity to the airbag module. The sensor system developed in accordance with the invention may however be programmed according to other criteria.

Several systems using other technologies have been devised to discriminate between the four cases illustrated above but none have shown a satisfactory accuracy or reliability of discrimination. Some of these systems appear to work as long as the child seat is properly placed on the seat and belted in. So called "tag systems", for example, whereby a device is placed on the child seat which is electromagnetically sensed by sensors placed within the seat have not proven reliable by themselves but can add information to the overall system. When used alone, they function well as long as the child seat is restrained by a seatbelt, but when this is not the case they have a high failure rate. Since the seatbelt usage of the population of the United States is only about 60% at the present time, it is quite likely that a significant percentage of child seats will not be properly belted onto the seat and thus children will be subjected to injury and death in the event of an accident.

The methodology of this invention was devised to solve this problem. To understand this methodology, consider two ultrasonic transmitters and receivers 110 and 111 (transducers) which are connected by an axis AB in FIG. 6. Each transmitter radiates a signal which is primarily confined to a cone angle, called the field angle, with its origin at the transmitter. For simplicity, assume that the transmitter and receiver are the same device although in some cases a separate device will be used for each function. When a transducer sends out a burst of waves, to thereby irradiate

US 6,397,136 B1

25

the passenger compartment with ultrasonic radiation, and then receives a reflection or modified radiation from some object in the passenger compartment, the distance of the object from the transducer can be determined by the time delay between the transmission of the waves and the reception of the reflected or modified waves.

When looking at a single transducer, it is not possible to determine the direction to the object which is reflecting or modifying the signal but it is possible to know only how far that object is from the transducer, that is a single transducer enables a distance measurement but not a directional measurement. In other words, the object may be at a point on the surface of a three-dimensional spherical segment having its origin at the transducer and a radius equal to the distance. Consider two transducers, such as 110 and 111 in FIG. 6, and both transducers receive a reflection from the same object, which is facilitated by proper placement of the transducers, the timing of the reflections depends on the distance from the object to each respective transducer. If it is assumed for the purposes of this analysis that the two transducers act independently, that is, they only listen to the reflections of waves which they themselves transmitted, then each transducer knows the distance to the reflecting object but not its direction. If we assume that the transducer radiates ultrasound in all directions within the field cone angle, each transducer knows that the object is located on a spherical surface A', B' a respective known distance from the transducer, that is, each transducer knows that the object is a specific distance from that transducer which may or may not be the same distance between the other transducer and the same object. Since now there are two transducers, and the distance of the reflecting object is known relative to each of the transducers, the actual location of the object resides on a circle which is the intersection of the two spherical surfaces A', and B'. This circle is labeled C in FIG. 6. At each point along circle C, the distance to the transducer 110 is the same and the distance to the transducer 111 is the same. This, of course, is strictly true only for ideal one-dimensional objects.

For many cases, the mere knowledge that the object lies on a particular circle is sufficient since it is possible to locate the circle such that the only time that an object lies on a particular circle that its location is known. That is, the circle which passes through the area of interest otherwise passes through a volume where no objects can occur. Thus, the mere calculation of the circle in this specific location, which indicates the presence of the object along that circle, provides valuable information concerning the object in the passenger compartment which may be used to control or affect another system in the vehicle such as the airbag system. This of course is based on the assumption that the reflections to the two transducers are in fact from the same object. Care must be taken in locating the transducers such that other objects do not cause reflections that could confuse the system.

FIG. 7, for example, illustrates two circles D and E of interest which represent the volume which is usually occupied when the seat is occupied by a person not in a child seat, C, or by a forward facing child seat and the volume normally occupied by a rear facing child seat, respectively. Thus, if the circle generated by the system, (i.e., by appropriate processor means which receives the distance determination from each transducer and creates the circle from the intersection of the spherical surfaces which represent the distance from the transducers to the object) is at a location which is only occupied by an adult passenger, the airbag would not be disabled since its deployment in a crash is desired. On the

26

other hand, if a circle is at a location occupied only by a rear facing child seat, the airbag would be disabled.

The above discussion of course is simplistic in that it is not take into account the volume occupied by the object or the fact the reflections from more than one object surface will be involved. In reality, transducer B is likely to pick up the rear of the occupant's head and transducer A, the front. This makes the situation more difficult for an engineer looking at the data to analyze. It has been found that pattern recognition technologies are able to extract the information from these situations and through a proper application of these technologies, an algorithm can be developed, which when installed as part of the system for a particular vehicle, the system accurately and reliably differentiates between a forward facing and rear facing child seat, for example, or an in-position or out-of-position forward facing human being.

From the above discussion, a method of transducer location is disclosed which provides unique information to differentiate between (i) a forward facing child seat or a forward properly positioned occupant where airbag deployment is desired and (ii) a rearward facing child seat and an out-of-position occupant where airbag deployment is not desired. In actuality, the algorithm used to implement this theory does not directly calculate the surface of spheres or the circles of interaction of spheres. Instead, a pattern recognition system is used to differentiate airbag-deployment desired cases from those where the airbag should not be deployed. For the pattern recognition system to accurately perform its function, however, the patterns presented to the system must have the requisite information. That is, a pattern of reflected waves from an occupying item in a passenger compartment to various transducers must be uniquely different for cases where airbag deployment is desired from cases where deployment is not desired. The theory described above and in more detail below teaches how to locate transducers within the vehicle passenger compartment so that the patterns of reflected waves will be easily distinguishable for cases where airbag deployment is desired from those where deployment is not desired. In the case presented thus far, it has been shown that in some implementations the use of only two transducers can result in the desired pattern differentiation when the vehicle geometry is such that two transducers can be placed such that the circles D (airbag enabled) and E (airbag disabled) fall outside of the transducer field cones except where they are in the critical regions where positive identification of the condition occurs. Thus, the aiming and field angle of the transducers are important factors to determine in adapting a system to a particular vehicle.

The use of only two transducers in a system is typically not acceptable since one or both of the transducers can be rendered inoperable by being blocked, for example, by a newspaper. Thus, it is desirable to add a third transducer 112 as shown in FIG. 8 which now provides a third set of spherical surfaces relative to the third transducer. Transducer 112 is positioned on the passenger side of the A-pillar (which is a preferred placement if the system is designed to operate on the passenger side of the vehicle). Three spherical surfaces now intersect in only two points and in fact, usually at one point if the aiming angles and field angles are properly chosen. Once again, this discussion is only strictly true for a point object. For a real object, the reflections will come from different surfaces of the object, which usually are at similar distances from the object. Thus, the addition of a third transducer substantially improves system reliability. Finally, with the addition of a fourth transducer 113 as shown in FIG. 9, even greater accuracy and reliability is

US 6,397,136 B1

27

attained. Transducer 113 is positioned on the ceiling of the vehicle close to the passenger side door. In FIG. 9, lines connecting the transducers C and D and the transducers A and B are substantially parallel permitting an accurate determination of asymmetry and thereby object rotation. Thus, for example, if the infant seat is placed on an angle as shown in FIG. 5, this condition can be determined and taken into account when the decision is made to disable the deployment of the airbag.

The discussion above has centered on locating transducers and designing a system for determining whether the two target volumes, that adjacent the airbag and that adjacent the upper portion of the vehicle seat, are occupied. Other systems have been described in the above referenced patents using a sensor mounted on or adjacent the airbag module and a sensor mounted high in the vehicle to monitor the space near the vehicle seat. Such systems use the sensors as independent devices and do not use the combination of the two sensors to determine where the object is located. In fact, the location of such sensors is usually poorly chosen so that it is easy to blind either or both with a newspaper, for example. Furthermore, no system is known to have been disclosed, except in patents and patent applications assigned to the assignee of this invention, which uses more than two transducers in such a manner that one or more can be blocked without causing serious deterioration of the system. Again, the examples here have been for the purpose of suppressing the deployment of the airbag when it is necessary to prevent injury. The sensor system disclosed can be used for many other purposes such as disclosed in the above-mentioned patent applications assigned to the same assignee as the instant invention. The ability to use the sensors for these other applications in generally lacking in the systems disclosed in the other referenced patents.

Considering once again the condition of FIGS. 2-7 where two transducers are used, a plot can be made showing the reflection times of the objects which are located in the region of curve E and curve F of FIG. 7. This plot is shown on FIG. 10 where the c's represent reflections from rear facing child seats from various tests where the seats were placed in a variety of different positions and similarly the s's and h's represent shoulders and heads respectively of various forward facing human occupants. In these results from actual experiments, the effect of body thickness is present and yet the results still show that the basic principles of separation of key volumes are valid. Note that there is a region of separation between corridors that house the different object classes. It is this fact which is used in conjunction with neural networks, as described in the above referenced patent applications, which permit the design of a system that provides an accurate discrimination of rear facing child seats from forward facing humans. Heretofore before the techniques for locating the transducers to separate these two zones were discovered, the entire discrimination task was accomplished using neural networks. There was significant overlap between the reflections from the various objects and therefore separation was done based on patterns of the reflected waves. By using the technology described herein to carefully orient the transducers so as to create this region of separation of the critical surfaces, wherein all of the rear facing child seat data falls within a known corridor, the task remaining for the neural networks is substantially simplified with the result that the accuracy of identification is substantially improved.

Three general classes of child seats exist as well as several models which are unique. First, there is the infant only seat as shown in FIG. 5 which is for occupants weighing up to

28

about 20 pounds. This is designed to be only placed in the rear facing position. The second which is illustrated in FIGS. 2 and 3 is for children from about 20 to about 40 pounds and can be used in both the forward and rear facing position and the third is for use only in the forward facing position and is for children weighing over about 40 pounds. All of these seats as well as the unique models are used in test setups according to this invention for adapting a system to a vehicle. For each child seat, there are several hundred unique orientations representing virtually every possible position of that seat within the vehicle. Tests are run, for example, with the seat tilted 22 degrees, rotated 17 degrees, placed on the front of the seat with the seat back fully up with the seat fully back and with the window open as well as all variations of these parameters. A large number of cases are also run, when practicing the teachings of this invention, with various accessories, such as clothing, toys, bottles, blankets etc., added to the child seat.

Similarly, wide variations are used for the occupants including size, clothing and activities such as reading maps or newspapers, leaning forward to adjust the radio, for example. Also included are cases where the occupant puts his/her feet on the dashboard or otherwise assumes a wide variety of unusual positions. When all of the above configurations are considered along with many others not mentioned, the total number of configurations which are used to train the pattern recognition system can exceed 500,000. The goal is to include in the configuration training set representations of all occupancy states that occur in actual use. Since the system is highly accurate in making the correct decision for cases which are similar to those in the training set, the total system accuracy increases as the size of the training set increases providing the cases are all distinct and not copies of other cases.

In addition to all of the variations in occupancy states, it is important to consider environmental effects during the data collection. Thermal gradients or thermal instabilities are particularly important since sound waves can be significantly diffracted by density changes in air. There are two aspects of the use of thermal gradients or instability in training. First, the fact that thermal instabilities exist and therefore data with thermal instabilities present should be part of database. For this case, a rather small amount of data collected with thermal instabilities would be used. A much more important use of thermal instability comes from the fact that they add variability to data. Thus, considerably more data is taken with thermal instability and in fact, in some cases almost the entire database is taken with time varying thermal gradients in order to provide variability to the data so that the neural network does not memorize but instead generalizes from the data. This is accomplished by taking the data with a cold vehicle with the heater operating and with a hot vehicle with the air conditioner operating. Additional data is also taken with a heat lamp in a closed vehicle to simulate a stable thermal gradient caused by sun loading.

To collect data for 500,000 vehicle configurations is not a formidable task. A trained technician crew can typically collect data on in excess of 2000 configurations or vectors per hour. The data is collected typically every 50 to 100 milliseconds. During this time, the occupant is continuously moving, assuming a continuously varying position and posture in the vehicle including moving from side to side, forward and back, twisting his/her head, reading newspapers and books, moving hands, arms, feet and legs, until the desired number of different seated state examples are obtained. In some cases, this process is practiced by con-

US 6,397,136 B1

29

fining the motion of an occupant into a particular zone. In some cases, for example, the occupant is trained to exercise these different seated state motions while remaining, in a particular zone that may be the safe zone, the keep out zone, or an intermediate gray zone. In this manner, data is collected representing the airbag disable, depowered airbag enabled or full power airbag enabled states. In other cases, the actual position of the back of the head and/or the shoulders of the occupant are tracked using string pots, high frequency ultrasonic transducers, or optically. In this manner, the position of the occupant can be measured and the decision as to whether this should be a disable or enable airbag case can be decided later. By continuously monitoring the occupant, an added advantage results in that the data can be collected to permit a comparison of the occupant from one seated state to another. This is particularly valuable in attempting to project the future location of an occupant based on a series of past locations as would be desirable for example to predict when an occupant would cross into the keep out zone during a panic braking situation prior to crash.

It is important to note that it is not necessary to train on every vehicle produced but rather to train on each platform. A platform is an automobile manufacturer's designation of a group of vehicle models that are built on the same vehicle structure.

A review of the literature on neural networks yields the conclusion that the use of such a large training set is unique in the neural network field. The rule of neural networks is that there must be at least three training cases for each network weight. Thus, for example, if a neural network has 156 input nodes, 10 first hidden layer nodes, 5 second hidden layer nodes, and one output node this results in a total of 1,622 weights. According to conventional theory 5000 training examples should be sufficient. It is highly unexpected, therefore, that greater accuracy would be achieved through 100 times that many cases. It is thus not obvious and cannot be deduced from the neural network literature that the accuracy of the system will improve substantially as the size of the training database increases even to tens of thousands of cases. It is also not obvious looking at the plots of the vectors obtained using ultrasonic transducers that increasing the number of tests or the database size will have such a significant effect on the system accuracy. Each of the vectors is a rather course plot with a few significant peaks and valleys. Since the spatial resolution of the system is typically about 3 to 4 inches, it is once again surprising that such a large database is required to achieve significant accuracy improvements.

Process For Training a Vehicle

The process for adapting an ultrasonic system to a vehicle will now be described. A more detailed list of steps is provided in Appendix 3. Although the pure ultrasonic system is described here, a similar set of steps applies when other technologies such as weight and optical or other electromagnetic wave systems are used. This description is thus provided to be exemplary and not limiting:

1. Select transducer, horn and grill designs to fit the vehicle.

At this stage, usually full horns are used which are mounted so that they project into the passenger compartment. No attempt is made at this time to achieve an esthetic matching of the transducers to the vehicle surfaces. An estimate of the desired transducer fields are made at this time either from measurements in the vehicle directly or from CAD drawings.

2. Make polar plots of the transducer sonic fields. Transducers and candidate horns and grills are assembled and tested to confirm that the desired field angles have been

30

achieved. This frequently requires some adjustment of the transducers in the horn and of the grill. A properly designed grill for ultrasonic systems can perform a similar function as a lens for optical systems.

3. Check to see that the fields cover the required volumes of the vehicle passenger compartment and do not impinge on adjacent flat surfaces that may cause multipath effects. Redesign horns and grills if necessary.
4. Install transducers into vehicle.
5. Map transducer fields in the vehicle and check for multipath effects and proper coverage.
6. Adjust transducer aim and re-map fields if necessary.
7. Install daily calibration fixture and take standard setup data.
8. Acquire 50,000 to 100,000 vectors
9. Adjust vectors for volume considerations by removing some initial data points if cross talk is present and some final points to keep data in the desired passenger compartment volume.
10. Normalize vectors.
11. Run neural network algorithm generating software to create algorithm for vehicle installation.
12. Check the accuracy of the algorithm. If not sufficiently accurate collect more data where necessary and retrain. If still not sufficiently accurate, add additional transducers to cover holes.
13. When sufficient accuracy is attained, proceed to collect 500,000 training vectors varying:
 - Occupancy (see Appendices 1 and 3):
 - Occupant size, position (zones), clothing etc
 - Child seat type, size, position etc.
 - Empty seat
 - Vehicle configuration:
 - Seat position
 - Window position
 - Visor and armrest position
 - Presence of other occupants in adjoining seat or rear seat
 - Temperature
 - Temperature gradient—stable
 - Temperature turbulence—heater and air conditioner
 - Wind turbulence—High speed travel with windows open, top down etc
14. Collect ~100,000 vectors of Independent data using other combinations of the above
15. Collect ~50,000 vectors of "real world data" to represent the acceptance criteria and more closely represent the actual seated state probabilities in the real world.
16. Train network and create algorithm using the training vectors and the Independent data vectors.
17. Validate the algorithm using the real world vectors.
18. Install algorithm into the vehicle and test.
19. Decide on post processing methodology to remove final holes (areas of inaccuracy) in system
20. Implement post-processing methods into the algorithm
21. Final test. The process up until step 13 involve the use of transducers with full horns mounted on the surfaces of the interior passenger compartment. At some point, the actual transducers which are to be used in the final vehicle must be substituted for the trial transducers. This is either done prior to step 13 or at this step. This process involves designing transducer holders that blend with the visual surfaces of the passenger compartment so that they can be covered with a properly designed grill that helps control the field and also serves to retain the esthetic quality of the interior. This is usually a lengthy process and involves

US 6,397,136 B1

31

several consultations with the customer. Usually, therefore, the steps from 13 through 20 are repeated at this point after the final transducer and holder design has been selected. The initial data taken with full horns gives a measure of the best system that can be made to operate in the vehicle. Some degradation in performance is expected when the esthetic horns and grills are substituted for the full horns. By conducting two complete data collection cycles an accurate measure of this accuracy reduction can be obtained.

22. Ship to customers to be used in production vehicles.
23. Collect additional real world validation data for continuous improvement.

More detail on the operation of the transducers and control circuitry as well as the neural network is provided in the above referenced patents and patent applications and is included herein as if the entire text of the same were reproduced here. One particular example of a successful neural network for the two transducer case had 78 input nodes, 6 hidden nodes and one output node and for the four transducer case had 176 input nodes 20 hidden layer nodes on hidden layer one, 7 hidden layer nodes on hidden layer 2 and one output node. The weights of the network were determined by supervised training using the back propagation method as described in the referenced patent applications and in more detail in the references cited therein. Naturally other neural network architectures are possible including RCE, Logicon Projection, Stochastic etc.

Finally, the system is trained and tested with situations representative of the manufacturing and installation tolerances that occur during the production and delivery of the vehicle as well as usage and deterioration effects. Thus, for example, the system is tested with the transducer mounting positions shifted by up to one inch in any direction and rotated by up to 15 degrees, with a simulated accumulation of dirt and other variations. This tolerance to vehicle variation also sometimes permits the installation of the system onto a different but similar model vehicle with, in many cases, only minimal retraining of the system.

The speed of sound varies with temperature, humidity, and pressure. This can be compensated for by using the fact that the geometry between the transducers is known and the speed of sound can therefore be measured. Thus, on vehicle startup and as often as desired thereafter, the speed of sound can be measured by one transducer, such as transducer 110 in FIG. 5, sending a signal which is directly received by another transducer. Since the distance separating them is known, the speed of sound can be calculated and the system automatically adjusted to remove the variation due to the change in the speed of sound. Therefore, the system operates with same accuracy regardless of the temperature, humidity or atmospheric pressure. It may even be possible to use this technique to also automatically compensate for any effects due to wind velocity through an open window. An additional benefit of this system is that it can be used to determine the vehicle interior temperature for use by other control systems within the vehicle since the variation in the velocity of sound is a strong function of temperature and a weak function of pressure and humidity.

The problem with the speed of sound measurement described above is that some object in the vehicle may block the path from one transducer to another. This of course could be checked and a correction not be made if the signal from one transducer does not reach the other transducer. The problem, however, is that the path might not be completely blocked but only slightly blocked. This would cause the ultrasonic path length to increase, which would give a false

32

indication of a temperature change. This can be solved by using more than one transducer. All of the transducers can broadcast signals to all of the other transducers. The problem here, of course, is which transducer pair does one believe if they all give different answers. The answer is the one that gives the shortest distance or the greatest calculated speed of sound. By this method, there are a total of 6 separate paths for four ultrasonic transducers.

An alternative method of determining the temperature is to use the transducer circuit to measure some parameter of the transducer that changes with temperature. For example the natural frequency of ultrasonic transducers changes in a known manner with temperature and therefore by measuring the natural frequency of the transducer the temperature can be determined. Since this method does not require communication between transducers, it would also work in situations where each transducer has a different resonant frequency.

The process by which all of the distances are carefully measured from each transducer to the other transducers and the algorithm developed to determine the speed of sound, is a significant part of the teachings of the instant invention. Prior to this, the speed of sound calculation was based on a single transmission from one transducer to a known second transducer. This resulted in an inaccurate system design and degraded the accuracy of systems in the field.

If the electronic control module that is part of the system is located in generally the same environment as the transducers, another method of determining the temperature is available. This method utilizes a device and whose temperature sensitivity is known and which is located in the same box as the electronic circuit. In fact, in many cases, an existing component on the printed circuit board can be monitored to give an indication of the temperature. For example, the diodes in the log comparison circuit have characteristics that their resistance changes in a known manner with temperature. It can be expected that the electronic module will generally be at a higher temperature than the surrounding environment, however, the temperature difference is a known and predictable amount. Thus, a reasonably good estimation of the temperature in the passenger compartment can also be obtained in this manner.

Another important feature of a system, developed in accordance with the teachings of this invention, is the realization that motion of the vehicle can be used in a novel manner to substantially increase the accuracy of the system. Ultrasonic waves reflect on most objects as light off a mirror. This is due to the relatively long wavelength of ultrasound as compared with light. As a result, certain reflections can overwhelm the receiver and reduce the available information. When readings are taken while the occupant and/or the vehicle is in motion, and these readings averaged over several transmission/reception cycles, the motion of the occupant and vehicle causes various surfaces to change their angular orientation slightly but enough to change the reflective pattern and reduce this mirror effect. The net effect is that the average of several cycles gives a much clearer image of the reflecting object than is obtainable from a single cycle. This then provides a better image to the neural network and significantly improves the identification accuracy of the system. The choice of the number of cycles to be averaged depends on the system requirements. For example, if dynamic out-of-position is required then each vector must be used alone and averaging in the simple sense cannot be used. This will be discussed more detail below.

When an occupant is sitting in the vehicle during normal vehicle operation, the determination of the occupancy state